JPRS-CST-94-009
23 May 1994

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Selections From China Today: National Defense S&T Undertakings

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JPRS-CST-94-009 CONTENTS *23 May 1994*

Selections From CHINA TODAY: National Defense S&T Undertakings

93FE0922A BEIJING CHINA TODAY SERIES in Chinese Vol I, 1992 pp 1-6, 62-64, 76-81, 108-110, 134-137, 147-148, 153-154, 187-188, 195-279, 342-366, and 375-381, and Vol II, pp 62-87, 87-99, 228-273, 274-288, 288-294, 426-427, 446.

[Text]

Volume I

Foreword

"China Today: Scientific and Technological Undertakings of National Defense" is now published. It is a significant achievement in China's science and technology and is worth celebrating.

Defense S&T is an important part of China's socialist modernization construction, but it is also an obscure field and people who devoted their hearts and minds to it are nameless heroes. With rich and detailed historical data, this book describes the development of China's defense S&T from the beginning and celebrates the devotion and bravery of China's defense S&T workers.

Directed by a decision of the Party Central Committee and the State Council, I have led and directed defense S&T for a very long time. The publication of this book reminds me of the difficult early years. I am very pleased to see the book published and also feel that some problems still warrant our exploration and thought.

In recent history China has repeatedly suffered from imperialist aggression and abuse. It was the urgent desire of the Chinese people and many patriots that China grasp modern S&T and establish a secure national defense. However, this could be achieved only in a socialist new China. Under the leadership of the Chinese Communist Party and the People's Government over the last 30 years, the defense S&T enterprise in China, like other endeavors, enjoyed unprecedented development and made world renowned achievements. The industrious and courageous Chinese people, relying on their own intelligence and resources, built a complete defense S&T system on the basis of a very backward economic and technological foundation of the old China. They have trained a high- quality defense S&T team, accomplished historical missions, mastered an effective nuclear self-defense power, developed new models of conventional weapons, and made breakthroughs in the high-tech arena of aerospace. These achievements have elevated China to the forefront of the world in national and military stature and greatly improved China's international standing. This has served as a vivid manifestation of the superiority of socialism.

If there is one lesson to be learned from the achievements of the new China defense S&T, it is that we should follow an independent, self-reliant path based on the national situation and reality in China.

(1) To ensure steady, sustained, and coordinated development in defense S&T, we must adhere to centralized, unified leadership and, whilekeeping in mind the big picture of national defense development strategy, properly handle the relationship between economic and defense development and the relationship between S&T modernization and modernization in industry, agriculture, and defense. After the birth of the New China, the Party Central Committee, the State Council, the Central Military Commission, and senior members of the Party, including Mao Zedong and Zhou Enlai, paid great attention to the role of S&T in the development of the socialist economy and the establishment of a modern defense. In different periods of history and based on the changes of the international strategic situation and the defense needs and national economic ability, they formulated a series of effective policies and directions for China's defense S&T development, and proposed programmatic goals and development plans. Later, under the unified leadership of the Party and the State, China took forceful action to build up research and testing facilities, organize an S&T team, mobilize the national resources, and make a concerted push to master quickly the frontier technology of the atomic bombs, hydrogen bombs, guided missiles, and artificial satellites. These efforts have also laid a material and technological foundation for future development. Facts have shown that the Party Central Committee, while leading economic construction, has paid attention to defense and made defense S&T development the main mission of defense modernization. The policy of concentrating the manpower and material and financial resources needed for prioritized construction was absolutely correct.

In a new historical period, the defense S&T front adhered to the policy of reform and combining the military and civilian sectors and obtained major achievements and contributions to the national economy. The Party Central Committee, centered around Comrade Jiang Zemin, proposed the correct policy of paying attention to both economic development and defense development. China's defense S&T will enjoy new successes as the nation's economic power becomes stronger.

(2) The basic policy for defense S&T development is to adhere to self- reliance and to improve China's ability to develop defense items independently. China is a major socialist country but needs to fundamentally change its backward state. To elevate the S&T standard and to achieve modernization, China cannot rely on others, so must do so with the intelligence and hard work of its own people. When China first began to develop its defense industry, the Party Central Committee put forth a policy of self-reliance supplemented by foreign aid. Because we have adhered to this correct policy, China's development of defense S&T was not controlled by others and, despite changes in the international arena and blockades and sabotage coming from different directions, proceeded along an independent path. Adherence to self-reliance did not mean exclusion. We must try to get all the help

possible, learn and absorb the advanced S&T results in the world, and apply those successful experiences that suit China's situation. We have actively pursued foreign aid in the past, now we must make an extra effort to take advantage of the favorable reform and open policy and, on the basis of mutual benefits, broadly develop international cooperation and exchange, selectively introduce advanced technology and research facilities, improve the capability of domestic manufacturing, accelerate development, and develop defense S&T on our own. With regard to foreign aid, however, we must keep a cool head and not harbor any unrealistic wishful thinking. History has proved that a backward nation is a nation that depends on and is controlled by others; we cannot buy China's modernization with money. To build a prosperous China and to achieve the Four Modernizations, we must rely on our own hard work.

(3) The policy of reform, openness, and combining military and civilian technology is necessary not only for the development of defense S&T during peacetime, but is also a correct approach to improve China'sability in domestic development and overall efficiency. The issue of a military-civilian combination was raised in the early phase of China's defense S&T construction. The military industry was asked to master two sets of skills so that they could deliver on the military production and at the same time apply the results of defense S&T to the construction of the national economy and to the production of civilian products. After the Third Plenum of the Eleventh Party Central Committee, the defense S&T industry adapted to the new situation of a reformed national economic and S&T system. The defense industry has on the one hand adhered to the strategic policy centered on economic development, adjusted product structure, R&D, and production and devoted the bulk of the resources to serve the national economic construction, and on the other hand consolidated its ranks, increased investments, improved technology reform, maintained a sensibly sized and structured modern defense S&T force, and shouldered the mission to conquer problems in defense S&T. China should continue to follow the principle of work division and accomplish major engineering R&D tasks by combining the S&T resources in defense and in other sectors of the country. The state should also take advantage of the strength and potential in the defense industry and emphasize the development of new, high-tech civilian engineering projects and products, and gradually establish a military- civilian defense S&T system.

(4) An important basis for success in defense S&T was to build a highly capable defense S&T team strong in both theory and practice. China's defense S&T workers love their motherland, socialism, and the Chinese Communist Party. They are also self-reliant, hard working, creative, cooperative, and selfless. They have not only created a golden age in defense modernization and material technology, but also cultivated a generation of leaders rich in spiritual culture. These results were achieved because the defense S&T front adhered to the Party leadership, insisted on doing ideological and political work, implemented the Party's policy regarding intellectuals, insisted on learning Marxist- communism and the thoughts of Mao Zedong, and guided defense research with material dialectics. We must treasure this honorable tradition and foster the results in the new historical setting. Science and technology are the primary factors in developing productivity and S&T workers are the pioneers for new productivity. We should establish a new trend in the society for respecting science, knowledge, and talent. We need to cultivate a new generation of S&T talent in the defense industry and let the old generation of S&T workers flourish.

(5) An important condition to accelerate the development of defense S&T is to respect objective rules and to strengthen scientific management. Based on the reality in China and the nature of China's defense S&T, a unified leadership system consisting of the Party Central Committee, the State Council, and the Central Military Commission was formed. The leadership management system combined research, production and application and made overall plans. The specific form of the large-scale defense S&T organization was based on objective rules that the defense development must obey. This system has worked well for improving scientific management, eliminating scattering and repetition, improving the overall efficiency of S&T investment, concentrating resources on major tasks, and accelerating the development of the defense industry. In today's new situation, defense S&T has adapted to the big environment of national reform, learned from foreign experience, and pursued reform and investigation in a number of directions; some new experience has been gained. We also recognize that reform of the defense S&T system must start from China's socialist economy. It must at once adapt to the requirement of planned commodity economy and conduct business according to the law of economics, and at the same time take into account the special nature of defense S&T and use social benefits, i.e., national security interests as the criterion. The tendency to pursue pureeconomic interests should be prevented. In the practice of reform, the two aspects should be rationally combined so that a Chinese-style defense S&T management system can be established, formalized, and institutionalized.

Today, a technological revolution characterized by new and high tech is swiftly growing in the world; it has become an increasingly important factor in gaging a country's national power and military might. People have increasingly recognized that science and technology is a form of productivity. The next 10 years will be a crucial decade in revitalizing China. China's defense S&T workers shoulder a grave historical responsibility of achieving the second step strategic goal of building up a national economy and social development. As an old soldier on the science and technology front, I expect and believe that comrades on the S&T front, with their honorable tradition, must be able to foster the advantages and take the lead in creating new results in China's socialist Four Modernizations.

Nie Rongzheng 27 November 1991

Chapter II

Section 1. Firmly Taking the Road of Self-Reliance

Improving Product Quality and Implementing Regulations of 70 Items for Industry

The "Great Leap Forward" of 1958 had a grave effect on the quality of military products. A number of military industries ignored product quality, blindly pursued value of production, operated without the rule of production and caused a widespread drop in military product quality. Aviation products were affected the most and not one aircraft was delivered over a period of three years because of failed quality. The Party Central Committee and the Central Military Commission were very disturbed by this. Having reviewed the product quality report of the Shenyang Airplane and Engine Plant by Minister Zhao Erlu [6392 1422 7120] of the First Ministry of Machine Building, the Central Military Commission called a special meeting of the standing committee members to hear more details from him. The Commission recognized the severity of the quality problem existed in the defense industry called for forceful action, and issued a clear policy of "quality first—increase quantity while maintaining quality. The Commission strongly rejected the erroneous viewpoint of pursuing quantity and production value without regard to quality and required all defense industries to adhere to the quality policy. In July and August of the same year the Party Central Committee approved and forwarded two reports by He Long [7729 7893] on defense industry production and construction and required the relevant departments and enterprises to ensure product quality by working on their ideology, technical management, production organization, and material and product inspection. The factories were told to reject all unqualified materials even if it meant a stoppage in production; the military was also ordered to reject unqualified products. Subsequently, the Secretariat of the Party Central Committee held special discussions on the quality of military products and demanded the leaders of provinces, municipalities, departments, and plants, mines and enterprises to strengthen quality inspection and to propose improvement measures.

In order to turn around the grave situation of poor quality in capital construction and military products, the Party Central Committee and the Central Military Commission authorized Director He Long of the Defense Industrial Commission to conduct a defense ministry/bureau/enterprise three-tier cadre conference in December 1960 to rectify the product quality problem. In the meeting, He Long summarized the 11-year experience of defense industry development and advocated continued readjustment of cadre ideology and product quality. He urged the attendants to adhere to the defense industry policies set by the Party Central Committee and the Central Military Commission and to contribute to the defense mission. This conference had a positive effect on the rectification of the chaotic management in the defense enterprises and the pompous working style and helped to establish the concept of quality first.

The three-tier cadre conference passed the "Instructions for starting a rectification campaign in the defense industry." Beginning in late January 1961, a 10-month rectification campaign centered on product quality was waged in the defense industry from the top down. Through this campaign, technology management systems were restored and improved, product quality gradually turned around, and the morale of the staff also changed significantly.

In order to overcome the confusion caused by the "Great Leap Forward" in many enterprises, including the defense industries, to guide the enterprises back to the right track, and to systematically consolidate the experience and lessons in leadership and enterprise management, the "R&D 14" was formulated. In addition, Deng Xiaoping [6772 1420 1627], Li Fuchun [2621 1381 2504], and Bo Yibo [5631 0001 3134] organized an extensive survey of industrial workers and formulated the "Regulations for State-Owned Industries and Enterprises (Draft)" (known as "Industry 70" for short). This document was signed by Mao Zedong on 16 September 1961 and put into trial implementation. This regulation required the enterprises to practice the factory manager responsibility system under the party committee. The chief engineer took full responsibility for the technical work. The enterprises were to make quality assurance and improvement their top priority, and the test manufacture and production of new products must be done following the regulations. The trial implementation of this regulation was very important for the policy of "readjustment, enforcement, strengthening, and elevating," for improving the management of enterprises, for restoring the normal order of production, for elevating the management standards, and for upgrading the product quality.

Adjusting the Overall Arrangements and Building Up the Third Line (Inland Area)

The three-line construction began in the mid-1960s in China. It was a vital action taken to protect the national security and the smooth progress of economic development and to improve the industrial layout for a possible war of invasion when China was faced with a hostile international environment In May and June 1964, the Party Central Committee made a strategic decision to "make strategic preparation and strengthen the construction of the three lines." It was decided that resources would be concentrated for the construction of inland and new constructions would be placed inland. The defense industry was also asked to construct the three lines and to begin survey and design immediately. The Office of Defense Industry immediately called a conference to study the preparation for three-line construction. It was

decided that the readjustment of one line would be done according to the principles of small scale, specialization, and cooperation; resources would be put together for the construction of the three lines. After the conference, the Office of Defense Industry organized the various defense ministries and conducted field survey and site selection in ten regions on the three lines; the activity was led by Zhao Erlu. On this basis, Director Luo Ruiqing [5012 3843 0615] submitted a report entitled "New Defense Industry Projects in Second-line and Third-line Regions" to the Party Central Committee in February 1965. In this report Luo put forth the principles and plans for three-line construction in the defenseindustry. Luo's report was approved by the Central Committee in March of that year; hence began the all-out construction of the three lines in the defense industry.

On the whole, the construction of the three lines improved the strategic layout of the defense S&T industry, built a number of behind-the-line bases for large-scale production and research, and developed and produced weapons urgently needed by the troops. The three-line construction was therefore very important for battle readiness, reinforcing defense, and developing the economy, S&T, and culture of the mountainous inland. In the construction of the three lines, all the workers fostered the honorable tradition of enduring hardship and devoting selflessly and worked hard to make contributions. However, the three-line construction was also hampered by an excessively large scope and long line, diffused sites, uncoordinated projects and errors; these problems caused severe difficulties in production, research, and staff's lives. Since 1983, the state has gradually made planned and systematic readjustments to the construction projects in the three-line regions for better efficiency in serving the defense development and the national economy.

In the first half of the 1960s, the defense industry in China has, under the leadership of the Chinese Communist Party, adhered to the policy of self-reliance and overcame many difficulties by hard work. They made quick breakthroughs in the technology of the atomic bomb and guided missiles, made considerable progress in conventional weapons, established several research institutes and experimental bases, unified the management system for defense industries and universities, made a start in forming a national network of research, production, testing, and education, and had more than 100,000 people working on frontier technologies in defense and conventional weapons. These developments laid a solid foundation for further progress in the defense S&T enterprise. In the meantime, the Party's policy toward intellectuals was readjusted and adhered to, and the errors in the "Great Leap Forward" and the anti-rightists movement were corrected. S&T workers were trusted politically, relied upon in the work, and taken care of in their lives. Their initiative and creativity were fostered and a promising new situation for producing results and talent had arrived. People praised this period as the "golden age" of China's defense S&T.

Section 3. Advancement of Conventional Arms and Equipment From Copy Production To Independent Development

Since 1960, China has concentrated its resources to achieve breakthroughs in frontier technologies in defense and has developed conventional weapons by relying on itself. Departments in defense and numerous scientists and technical staff diligently adhered to the policy decision by the Central Military Commission that China should strengthen its weaknesses in conventional weapons and at the same time step up the effort to develop and improve new weapons. After a few years, the quality of China's conventional weapons has improved, the variety has increased, the performance has improved, and the compatibility has also improved. By 1965, 50 percent of the products approved by the Military Product Typing Committee of the State Council were designed by the Chinese. This signaled that China's conventional weapon development has moved from copying to independent development.

(1) Better Progress Made in Development of Army Weapons Systems and Equipment

In the late 1950s, weapons research institutes were established. Havingmastered emulation techniques, China gradually began its own weapons development projects. In 1960 the expanded Central Military Commission proposed a policy to improve the firepower, attack capability, defense capability, and mobility of army weapons. Based on this, the Defense Science Commission and the Office of Defense Industries strengthened China's ability to develop indigenous weapons while at the same time improved existing systems. By the mid-1960s, China had not only completed the development of systems it urgently needed, but also developed independently within a very short time a series of new weapons systems meeting Chinese needs.

In 1958, in order to deal with high-altitude hostile aircraft, China introduced from the Soviet Union medium to high-altitude, surface-to-air missiles and named the copied version "Hong Qi (Red Flag) No. 1" (HQ-1). In July 1958, Peng Dehuai [1756 1795 2037] emphasized in the expanded Central Military Commission meeting that: "We must actively engage in the research of surface-to-air missiles." In 1960, after the Soviet Union recalled their experts in China, Nie Rongzheng called for the production of the HQ-1 without outside help. In April 1962, Nie further pointed out in a business meeting of the Military Science Commission that, to master the technology of the HQ-1, China must first conduct reverse engineering. To do so, the Party Central Committee decided to have the Fifth Academy and the Third Ministry of Machine Building take the lead. It also organized close to 30 units in China to assume the R&D and production duties for thousands of materials and components. Bo Yibo was specifically responsible for making sure that the tasks were coordinated and carried out. In 1964, the HQ-1 surface-to-air missile was successfully copied. This indicated that

China had established the emulation and fabrication capability and had laid the foundation for independent development of the new surface-to-air missiles.

Light anti-aircraft artillery was important and they were effective weapons for low-altitude air defense at the time. However, the anti- aircraft artillery copied from the Soviet Union was very bulky and suffered from poor mobility. There were many complaints from the troops and improvements were sorely needed. In 1965, a twin 37mm anti-aircraft gun was successfully developed, based on the single-barrel 37mm Soviet model. This weapon played a major role in aiding Vietnam against the United States.

In order to improve the mobile firepower of the artillery, China's Central Military Commission made the rocket a priority as early as 1958. In 1963, the artillery and the Third Ministry of Machine Building successfully developed China's first generation of 107mm and 130mm rockets. In actual combat these weapons proved to be very powerful and were widely praised by the troops. In 1961, in a Central Military Commission meeting on equipment systems, new mortars were chosen to be a high priority item for development. A cooperative effort by the Chinese artillery and the Fifth Ministry of Machine Building led to the development of 60mm and 120mm mortars in the mid-1960s. This was followed by efforts to reduce the weight of the weapons.

In order to satisfy the complex weather and terrain conditions of China and the combat requirements in different regions, Peng Dehuai proposed in 1958 that China emphasize medium and light tanks, amphibious tanks, and armored vehicles. In 1959 the Central Military Commission decided that tank development should stress medium and light models and there should also be a corresponding development effort for amphibious tanks. In the mid-1960s, China developed light tanks, amphibious tanks, and armored vehicles with tracks suitable for fighting in China's rice patties, rivers, lakes, mountains, and coasts. These weapons improved the mobility of tanks and mechanized troops in south China and were an important milestone toward domestically manufactured weapons systems forChina's armored troops.

The Central Military Commission requested a weight reduction for the army weapons and ordered design improvement and simplification for the unwieldy weapons copied from the Soviet Union. Based on these requests, the weapon industry department developed in 1963 a 7.62mm automatic rifle that combined the roles of an assault rifle and a semiautomatic rifle. It also developed a silenced assault rifle for surveillance units. Both weapons were very popular among the troops.

(2) Copy Production of Military Aircraft Turned Into Independent Development

In a 1960 expanded meeting of the Central Military Commission, a development policy was put forth for the Chinese Air Force. The policy emphasized high-altitude, high-speed fighters. It required a performance improvement of the Jian-6 (a copy of the MIG-19) followed by a trial development of the Jian-7 (a copy of the MIG-21). Scientists and technical staff at the Sixth Academy and the Third Ministry of Machine Building heeded the principle of "first master the technology, then gradually design our own." They worked hard to solve the quality problems in copying the Soviet models and began to develop China's own military aircraft.

In early 1961, the Office of Defense Industries decided to reproduce the Jian-6 aircraft that was plagued with quality problems. After 2 years of hard work, the quality problems were solved in 1963. For this, the Central Military Commission congratulated the workers in a letter that said: "This advance in China's defense capability is to be celebrated. It also marks a turning point in China's aerospace industry." By copying the Jian-6, China mastered the entire manufacturing technology of supersonic fighters and elevated its level of aircraft production. In 1964, the design for the Pili-1 air-to-air missile, to be used on the Jian-6, was finalized.

Before China began copying the Jian-7 high-altitude, high-speed fighter, Lo Ruiqing demanded that the Sixth Academy devote its major technical resources to the MIG-21 technology. Because of the thorough effort, the copying of the Jian-7 was completed ahead of schedule in June 1967. The copying of the Jian-7 laid down a sound foundation for independent design and production of new fighters. After research, production, and almost a year of planning by the user department, a report entitled "Proposal To Develop New Fighters" was submitted to the Central Military Commission by the Office of Defense Industries and the Defense Science Commission in April 1965. The proposal was approved by Lo Ruiqing in May and the effort to independently develop new high-altitude, high-speed fighters began subsequently.

In order to meet the needs of the Air Force, China also began the development of attack aircraft. In as early as March 1958, Air Force commander Liu Yalou [0491 0068 2869] raised the need for an advanced attack aircraft. With the approval of then Deputy Chief of Staff Chen Geng [7115 6342], work was initiated to develop the supersonic Qiang-5. The preliminary design was finalized at the end of 1965. The Qiang-5 attack aircraft was designed and developed by the Chinese themselves. It was a durable, high-performance aircraft and was widely used in the Chinese Air Force. Its successful development was highly significant to China's national defense.

(3) Naval Vessels Entering the Period of Overall Copy Production

Beginning in the 1960s, China entered a phase of across-the-board copying of naval vessels based on manufacturing transfer. In Septemberand October 1960, the expanded meeting of the Central Military Commission specifically put forth a naval development policy based

on submarine and fast attack craft. In 1962, Nie Rongzheng pointed out in a briefing by the Seventh Academy that the R&D mission of the Academy for the next 5 years should be concentrated mainly on the development of torpedo boats, torpedo submarines, and torpedoes. In September 1963, Luo Ruiqing stated in his report to the Central Committee regarding "Some issues in the shipbuilding industry," that, in the next few years, China should first work on torpedo boats, submarines, and torpedoes, then on guided missile submarines, missile boats, and ship-to-ship guided missiles. Based on that, the Defense Science Commission and the Defense Industrial Commission organized an effort to develop torpedo boats, submarines, and torpedoes and to copy the manufacturing of foreign boats in China. An effort was also made to design medium and small-sized surface vessels. After a few years of work, China succeeded in developing its own torpedo boat in 1965. These boats were urgently needed for coastal operations at the time and they were developed using Chinese materials and domestic facilities. Medium-sized diesel-powered torpedo submarines were also transferred and produced in the same year and put into service. In 1966, China produced its first gas torpedo. While concentrating on the development of torpedo boats, submarines, and torpedoes, China also worked on guided missile submarines, missile boats, and ship-to-ship guided missiles. Efforts were made to copy the manufacturing process and to use domestic materials and equipment. The problem of welding special steel and the problem of cavitation erosion of the propellers were solved. The assembly and production of small missile boats, large missile boats and large guided missile submarines were successfully developed. Work also began on the improvement and modification of submarines. Based on instructions from Nie Rongzheng to prioritize the copying of naval defense missiles, the Defense Science Commission devoted its resources to copy the Shangyou-1 ship-to-ship missile in 1964.

In this period China also developed anti-submarine escort vessels and gunboat escort, began the preparation for developing a nuclear powered submarine and guided missile destroyers, and initiated studies of medium-sized torpedo submarines.

(4) Military Electronic Equipment Extricated Basically From Copy Production Phase

China's radio electronics technology had a very weak base and could not satisfy the needs for developing border technology and conventional weapons. For this reason, considerable attention was given by the Central Committee and the Central Military Commission to the development of defense electronics. In August 1958, after the expanded meeting of the Politburo met and discussed the "Second 5-Year Plan," Nie Rongzheng wrote a letter to the Central Committee leadership and recommended that attention be given to the study and production of radio electronics in future planning for capital construction and facilities. In November 1959, the Central Military Commission stated in a report to the Central Committee on the development plan for the last 3 years of the Second 5-Year Plan, that "radio electronics is the weakest link in China's defense industry. The original allocation for 1960-1962 must be increased." In 1960, the Central Military Commission again set a specific policy for developing electronics technology. With the attention of the Central Committee and the Central Military Commission and the gradual establishment of research institutes, China's defense electronics developed quickly. It basically outgrew the copying phase and began to stand on its own. By the mid-1960s, China's defense electronics not only satisfied the need for developing the "two bombs" and other urgently needed conventional weapons, but also made some breakthroughs in radar, communications, and electronic computers.

To ensure that China's first atomic bomb exploded in 1964, R&D departments finished the development of control and test equipment in time and provided various radiation detection instruments. In 1965, China successfully copied the construction of a surface-to-air guided missile station.

In order to improve the anti-jamming ability of air defense radar and the detection of hostile aircraft in mountains, jungles, rain, and in clouds, China developed its own low-altitude warning radar and height-finder radar in 1963. In 1964, China improved the performance of its gunsight radars and airborne firing radar in terms of counter-surveillance and counter-jamming ability. These improvements were very important for air combat.

The continuous development of semiconductors led to the miniaturization of defense electronics and promoted the transition from first-generation to second-generation electronics. In order to improve the mobility of troops, field communications equipment used extensively by military units up to the division level were miniaturized. Some semiconductor tactical radio stations were also developed. In the area of large short-wave communications equipment, single-sideband technology was mastered and several single-sideband short-wave stations were built. Considerable results were also obtained in multichannel communications. Wired radios, microwave relay, and troposphere scattering generators came on the scene. These instruments improved defense communications capabilities. By 1965, China had developed some semiconductor computers and thus entered the second generation of defense electronics.

Chapter III

Section 2. Breakthroughs in the Most Advanced Defense Technology

(3) Successful Development of the Nuclear-Powered Torpedo Submarine

The development of the guided missile nuclear submarine was approved by the Central Committee in June

1958. A 3-year effort produced some initial results in the hull design and in the nuclear power plant. In March 1963, the Central Special Committee decided to put the project on hold because of temporary difficulties in the national economy and a lack of research resources. However, a portion of the research effort was retained to work on technological breakthroughs. In the mid-1960s the national economy improved and the Central Special Committee decided in March 1965 to reinstate the project as a national project and to launch a full-scale R&D effort. It also asked the Second Ministry of Machine Building to complete a land-based reactor by 1970 as an intermediate step toward a nuclear-powered submarine. The approach was to verify the nuclear reactor first on land and then to install it on the submarine. In order to shorten the development time for the complicated technology of guided missile nuclear submarine, the Central Special Committee decided in August of the same year that there would be two phases in the development. The first step was to develop a nuclear torpedo submarine and to solve major technological problems of a nuclear-powered submarine and an anti-submarine torpedo. The second step would be to develop a guided missile nuclear submarine and to solve the key technology for a submarine-to-land guided missile and its launch system. The Central Special Committee further decided that the first nuclear torpedo submarine should have its maiden voyage in 1972. The submarine should meet all the major tactical requirements so that it could be delivered to the Navy as a warship. The Central Special Committee demanded a cooperative and coordinated effort from the participating departments and committees of the State Council so that the nuclear submarine could be developed expediently.

In 1967 the Defense Science Commission organized and evaluated the hull design for the nuclear torpedo submarine based on tactical andtechnical requirements approved by the Central Military Commission. The nuclear submarine technology was complex and required broad cooperation. In order to satisfy the equipment needs of this major engineering project so that the development could proceed in a timely fashion, the Central Special Committee required the various departments to treat the development of instruments and equipment of the nuclear submarine as a national priority. All business was conducted according to the document issued by the Central Special Committee for the development of the atomic bomb: "Regulations for the Development of Atomic Energy Devices and Instruments." In May of that year, the Central Special Committee further specified that equipment urgently needed in the development of the nuclear submarine should be provided in a timely manner by the State Planning Commission, the Ministry of Materials, and other relevant departments. These departments responded to all the needs and often made special efforts beyond their regular operations to solve the coordination problem. Together with the Office of Defense Industries, the Defense Science Commission also held a number of large coordination meetings. In the summer of 1967, Liu Huaqing [0491 5478 3237] chaired a large coordination meeting attended by several hundred officers and technical cadres of plants and research institutes. Nie Rongzheng spoke and asked the cadres to work hard for the development of the nuclear torpedo submarine for the great cause of national defense. Later, the State Planning Commission and the Office of Defense Industries also organized a development effort for equipment systems and new materials. They organized more than 1,600 plants, giving the submarine development effort strong support.

In order to strengthen the coordination and organization, the Central Military Commission approved the establishment of the Nuclear Submarine Engineering Office under the Defense Science Commission in February 1968. In October 1969, the State Council and the Central Military Commission also decided to form a Nuclear Submarine Engineering Leadership Group under their supervision. Offices were established under the group to take care of day-to-day business. Various industrial ministries, research institutes, provinces, municipalities, and military regions also formed their own offices or groups for nuclear submarine engineering. A top-down chain of command was therefore established. Organizationally, the State Council and the Central Military Commission's Nuclear Submarine Engineering Leadership Group led the various research departments, manufacturing plants, and universities in conducting the development project. Problems that arose in the tests were addressed by timely inspection and coordination. The quality and progress of the nuclear submarine development were solidly guaranteed.

Based on the needs for ocean tests and requirements of the associated weapons systems, the Central Special Committee approved the establishment of three test fields for torpedoes, underwater sound, and submarine-to-land guided missiles. The State Council and the Central Military Commission decided to include the building of a dual-plane, self-guided anti-submarine torpedo as part of the nuclear submarine engineering project and gave it a high priority. With the hard work of all the participants, the torpedo plant and the three test sites were built and began to assume production and test missions.

Construction of the nuclear submarine assembly plant and the land-based nuclear reactor was vital to the development schedule. Mao Zedong signed two telegrams in 1968 and 1969, respectively, ordering the Shenyang Military Region to support the construction of the nuclear submarine general assembly plant and the Chengdu Military Region to lead the construction of the land-based nuclear reactor. Deputy Commander Jiang Yonghui [3068 2340 6540] and Zhang Fengxian [1728 1496 0341] led their troops working at the construction site around the clock and finished the job as required. The land-based nuclear reactor was also built aheadof schedule and was completed in April 1970.

The power test of the land-based reactor involved safety and quality issues and was therefore a key project. In July 1970, before the onset of testing, Zhou Enlai [0719 1869 0171] invited the major players of the reactor project to Beijing for a briefing. Also invited were experts from the Second Ministry of Machine Building and Qinghua University. Zhou approved the test and, heeding the experts' recommendations, requested preparation for possible accident scenarios. The power was to be raised in steps and an expert group approved by Zhou was sent to the test site. The power test went smoothly and the test data showed that the overall design of the nuclear power plant was successful and the device was ready to install on the submarine.

In April 1971 China's first nuclear submarine began a series of dock tests. On 16 June 1971 the Central Special Committee reviewed the preparation data for the reactor startup test and the sailing test. The Committee decided that, for the first tests, work must proceed in stages, following the order of dockside tests, sailing tests,long-distance sailing tests, and deep-water tests." Following the orders of the Committee, the Nuclear Submarine Test Leadership Group carefully organized the staged tests. The dockside test and sailing test were accomplished in August 1971 and April 1974, respectively. Test results showed that the torpedo submarine had a high cruising speed under water, a long range, and good concealment. The design and construction of the submarine were both sound and the vessel was ready for delivery to the Navy.

Chapter IV

Section 2. Concentrating Efforts To Fulfill the "Three Grasps" Task

In order to accomplish breakthroughs in frontier defense technology, the Central Committee, the Central Military Commission, and the Central Special Committee decided on 18 September 1977 that resources must be concentrated on three priority missions: the intercontinental ballistic missile (ICBM), the submarine-to-land guided missile, and the communications satellite. This important policy decision gave defense S&T a tremendous boost. The completion of the three missions also promoted the development of conventional weapons and other projects.

(1) Oceanic Instrumentation Fleet Build-Up

Conducting a full range of flight tests for the ICBM and to develop space technology required a ship-based mobile tracking and measurement system on the ocean. In August 1965 Zhou Enlai chaired a Central Special Committee meeting and decided that the Defense Science Commission should come up with a specific plan. In July 1967 the Defense Science Commission invited the general staff department, the Office of Defense Industries, the Navy, the Chinese Academy of Sciences, relevant industrial ministries, and research institutes to study and propose a development plan for an oceanic instrumentation fleet. In view of the need to understand the hydraulic, meteorological, and geological situation of the test area and the need to conduct escort operations, it was recommended that escort and supply vessels be developed simultaneously with the oceanic instrumentation fleet. In June 1968 Mao Zedong, Zhou Enlai, and the Central Military Commission approved the principle of the proposed plan. The Defense Science Commission immediately organized the Seventh Academy and the Northwest Joint Missile Test Base to begin the overall design for the survey vessel. The plan was submitted to the State Council and the Central Military Commission in July 1970. In December 1970 Zhou Enlai chaired a Central Special Committee meeting, in which the project was classified as anational priority project. Also approved in the meeting was the formation of an oceanic instrumentation fleet engineering leading group consisting of leaders from participating departments and military services, to enhance the supervision of the engineering development. However, due to the interference by the "Great Cultural Revolution," the development effort was thwarted.

In April 1972, on behalf of Zhou Enlai, Ye Jianying [0673 0494 5391] called a military committee working conference to review the progress. Zhang Chunchiao [1728 2504 2890) stated in the meeting that Shanghai would have difficulty in shouldering the bulk of the ship building task. Ye stressed that the project could not possibly be halted and work must proceed despite difficulties. The conference decided that the survey vessel development would push on and the scope of the Phase I engineering would be six vessels of five different models, most of them would be built in the Shanghai region. Later, due to changes of measurement procedures in the ocean target zone and for added assurance, six additional vessels were added. In 1973 Zhou Enlai approved the revised development report for the survey vessels, clarified the guiding principles, and ordered work division among the various systems. Zhou decided that the oceanic instrumentation fleet engineering leading group should be supervised directly by the State Council and the Central Military Commission. Zhou Xihan [0719 1585 3352] was appointed group leader, and Qian Xuesen [6929 1331 2773] and Yu Qiuli [0151 4428 6849] were appointed deputy group leaders; the office was located in the Navy. The leadership group and its office took command and after extensive study and discussion established a rational, general system plan for assigning tasks. By 1975, different ship models were under construction. Survey ship bases were also under construction. In November 1976 the State Council and the Central Military Commission decided to eliminate the oceanic instrumentation fleet engineering leading group; its office in the Navy was moved to the Defense Science Commission and the development task was given to the Defense Science Commission. In September 1977, Zhang Aiping [1728 1947 5493] and Qian Xuesen chaired a coordinating meeting in Shanghai. They asked for an accelerated development and construction schedule for the survey vessels and specified that two of

the vessels should complete their test run, special equipment installation, and at-sea coordination by the end of 1979. They demanded that the development units pledge and guarantee the completion of the assigned mission. The departments involved in the project then took some forceful measures and devoted great effort to technological breakthroughs in key equipment and quality assurance. A liaison group of the Defense Science Commission was stationed in Shanghai to coordinate with the Fourth, Sixth, and Seventh Ministries of Machine Building, and with the municipality of Shanghai for intensive on-location monitoring of the project progress. In July 1979, the Defense Science Commission held another coordination meeting in Shanghai, this time chaired by Li Yaowen [2621 5069 2429] and Chen Bing [7115 1755], to further solve the problems in special equipment installation. In the meantime, supervision was intensified, planning was made more intensive, and system engineering methods were used for on- site organization in the installation effort. All the tasks were accomplished according to the master plan. In October 1979, Zhang Aiping, Chen Bing, and Qian Xuesen joined other leaders from the First, Fourth, Sixth, and Seventh Ministries of Machine Building, the Shanghai Office of Defense Engineering, and the survey vessel base, to inspect the progress of construction in Shanghai. Zhang Aiping held an on-site meeting for the Central Special Committee and made decisions on a number of relevant issues. These included verification of equipment quality, improvement of reliability, problems with equipment systems and their installation aboard ship, spare parts and components, and command organization for overall communications and off-shore tests. With the coordinated effort, equipment was installed and tested and the all-shipcoordination and flight calibration were all completed by the end of the same year. The performance basically satisfied the requirements for the tactical and technical mission. By 1980, the development tasks were completed for two survey ships (Yuanwang-1 and Yuanwang-2), one research vessel (Xiangyanghong-10), and three each of rescue vessels, tugs, and supply ships. A total of 12 ships of five different models were built. The survey vessels were China's first generation of ocean survey and tracking stations. The other ships were also China's first-generation oceanic instrumentation vessels. Their overall performance and major equipment were the most advanced in China at the time. The establishment of the oceanic instrumentation fleet made China the fourth country in the world, after the United States, the Soviet Union, and France, to have an ocean survey and tracking capability. It formed a land-sea communications network for measurement and monitoring and provided a good tracking and monitoring system for the development of the three high-priority missions and other aerospace flight tests. It has contributed to China's development of its frontier defense technology.

(6) Development of Nuclear-Powered Missile Submarine

Based on the decision of the Central Special Committee to first develop the nuclear torpedo submarine and then develop the guided missile submarine, the study of the overall design for the guided missile submarine and submarine-to-land missile system began shortly after initial results were obtained in the nuclear torpedo submarine project. In 1969 the State Planning Commission, the Office of Defense Industries, and the Defense Science Commission made some specific assignments for the guided missile submarine project. The Seventh Academy was assigned to develop the missile bay and the launch device, the Second Ministry of Machine Building was picked to design and build the nuclear power device, and the Seventh Ministry of Machine Building was given the task of developing the submarine-to-land guided missile. Other participants in the submarine weapons system development included the First and Fourth Ministries of Machine Building, 15 other departments and institutes, 24 provinces and municipalities, and some 2,000 plants and research laboratories. In 1970 the construction of the first guided missile nuclear submarine began but was hampered by the "Great Cultural Revolution." In addition, because of the high degree of technical difficulty in developing the submarine-to-land guided missile and the launch system, there were many technical obstacles and progress was slow. In 1977, after reorganization, the development project returned to normal and progress accelerated. In the development process, attention was preferentially given to the design and construction of the submarine and not enough attention was given to the torpedo, resulting in a void in the weapon system. Deng Xiaoping [6772 1420 1627] stressed repeatedly that the nuclear submarine alone was not a weapon. Because of this, Zhang Aiping rigorously supervised work on the submarine and the torpedo, and paid special attention to the quality problems encountered in the project. In 1983, the first submarine was completed and delivered to the Navy for training use. Key technologies in the submarine-to-land guided missile system and its installation were subsequently solved. Launching tests of model missiles from the nuclear submarine were conducted and succeeded, proving that the overall design was correct and that the submarine, missile, and launching system were compatible. With this, China became the fifth nation in the world to have a guided missile nuclear submarine.

Section 3

(3) Improving the First Generation of Naval Vessels

In 1977 the Central Military Commission decided that the development ofthe Navy equipment should still be focused on the submarine, guided missile boats, anti-ship missiles, and torpedoes. In order to improve existing vessels, the Central Military Commission decided in 1978 that the quality of nuclear torpedo submarines, and destroyers, mid-sized torpedo submarines, large missile boats, and anti-submarine escorts should be improved and the systems should be made

more compatible. In November 1978, the Central Military Commission approved the formation of an engineering leadership group for the above five types of vessels and assigned Zheng Hantao [6774 3352 3447] to be the group leader (later replaced by Fan Mohan [5400 1970 7281] in March 1981.) After several years of work, the upgrading of the five types of vessels produced significant results. Several hundred upgrading and technical breakthrough tasks proposed in 1979 were all completed in 1984.

In 1977, at the request of the [PLA] General Staff and the Office of Defense Industries, the first generation Duihai guided missile escort vessel was entirely redesigned. In the early 1980s, a dual 100mm gun system was added and systems were developed for the weapons, electronics, and power plant. The remodeled vessel was named Duihai-I. In 1983 eight Yingji-8 anti-ship missile fixed launchers replaced the original two Shangyou-1 guided missile twin joint rotation launchers. A new electronics warfare system was also added. The improved model was called the Duihai-II guided missile escort. After the escorts were placed in service, a series of escorts developed and some were also exported.

To meet the modern warfare requirements, China modernized its first generation destroyers in the early 1980s. The emphases were: to upgrade the weapons, to improve the electronics, and to automate the battle command. In this period China upgraded its large guided missile boats, four-launcher torpedo boats, anti-submarine escorts, minesweepers, minelaying vessels, and landing craft. By 1984, all the development and upgrading of the first generation vessels were completed and the performance has all improved.

While working on the first-generation ships, the Central Military Commission also decided to develop the second-generation ships and weapons to meet the Navy's needs. These systems included new models of conventional submarine, destroyers, guided missile frigates, light anti-submarine escorts, large missile boats, and anti-submarine torpedoes.

To change the previous practice of developing the ships and weapons separately, the Central Military Commission repeatedly stressed that the development of naval weapons must adhere to the principle of "five compatibilities," namely, compatible planning, compatible design, compatible modeling, compatible production, and compatible delivery. The purpose was to ensure coordinated progress in shipbuilding and weapons development. The responsible departments conscientiously carried out the orders of the Central Military Commission. Weapons developed in this period included the Model 76 twin 37mm gun system, the Model 66 twin 57mm gun, the twin 100mm gun system, and the copy of the Model 69 twin 30mm gun system. These weapons systems formed a new series of ship-board guns. Design improvement and development were also made for the following naval weapons: Model 81 rocket depth charge anti-submarine system, models Yu-4A and Yu-4B acoustic anti-ship torpedoes, and the Haiying-2A, Haiying-2B, Shangyou-IA, and Yingji-6 anti-ship missiles.

In the mid-1980s new Chinese-made ships and weapons were developed and put into service. This new equipment has greatly improved the combat capability of the Chinese Navy.

Chapter V

Section 3. Coordinated Development of Defense S&T

(2) New Progress in Strategic Missile and Nuclear Weapons Systems

The successful completion of the "three priority" missions marked the serialization of the land-based short-range, mid-range, mid-to-long range, and intercontinental strategic guided missiles. It also marked the end of first-generation submarine-to-land nuclear guided missiles. China had entered the development phase for second-generation strategic weapons.

In May 1985 China made its first mobile launch of a surface-to-surface solid-fuel strategic missile. Lessons were learned from the failed submarine-to-land solid-fuel guided missile and a modified design was completed in September 1988. This indicated that China had mastered the new technology of solid fuel, mobile launcher-s,and underwater submarine launching, and had gained useful experience for the development of the second-generation strategic missiles.

In this period China had made new breakthroughs in its nuclear weapons program. While finalizing the warhead design for the various strategic guided missiles, China conducted research into new design theories and manufacturing technology and achieved numerous results. Under the leadership of the Defense Science Commission, there was close coordination between the nuclear weapons research institutes and the target ranges. A series of tests was successfully conducted. New nuclear weapon theories were evaluated and a solid foundation was laid for future development.

China has conducted necessary and limited nuclear tests and developed nuclear weapons for defense purposes. China continues to improve and perfect its nuclear weapons and makes new breakthroughs in design theory to ensure the safety of China and to contribute to the keeping of world peace.

From April to May 1988 China's first nuclear submarine conducted deep- diving, underwater high-speed cruising and deep-sea torpedo launch tests in the South China Sea. Tests showed that the ocean access system had excellent strength and seal and the torpedo system operated normally, meeting the design requirements. The success of the deep-water tests of China's first nuclear submarine was another major achievement of China's strategic weapons development program. It showed that China's first-generation nuclear submarine was designed

and built properly and led the way to the second-generation nuclear submarines.

Chapter VI. Development of Nuclear Weapons

Nuclear weapons make use of the energy released from self-sustained nuclear fission or fusion reactions for mass killing and destruction. In 1955 China decided to initiate its nuclear industry and to develop its nuclear weapons. After 30 years, China has independently mastered the technology of atomic and hydrogen bombs, and has made major advances in the development of new nuclear weapons.

Section 1. Preparation for the Development of Nuclear Weapons.

(I) Establishment of nuclear scientific research center

The development of nuclear weapons relies on the establishment of nuclear science and technology and a nuclear-industry. Before the formation of the People's Republic of China, although there was the Atomic Research Institute in Beijing and the Nuclear Physics Laboratory under the Institute of Physics in Academia Sinica,the total number of researchers was less than 10 and there was not even a small accelerator.Nuclear science and technology was basically a void in China at that time.

The New China stressed the initiation and development of nuclear science and technology. In April 1950 the Chinese Academy of Sciences (CAS) established the Institute of Modern Physics. Its main mission was to establish a foundation for nuclear science and technology and prepare for nuclear energy application and development. The director of the institute was Wu Youxun [0702 2589 6064] and the deputy director was Qian Sanqiang.

The Institute of Modern Physics had some renowned scientists but there were too few of them and their specialties did not complement each other. The pressing obligation at the time was to attract talent and to expand the ranks of science research. With Zhou Enlai's interest and support, the Institute attracted theoretical physicist Peng Huanwu from Qinghua University and experimental physicist Wang Ganchang [3769 3227 2490] from Zhejiang University. In 1955, 13 scientists and overseas Chinese students came to the Institute from Europe and the United States, some of them risking their lives to do so. The famous nuclear physicist Zhao Zhongyao [6392 1813 1031] was illegally detained by American troops in Japan as he was returning to China from the United States via Japan. It was only with the protests from the Chinese scientific community and civil organizations, and the support of friends in the scientific community in America and other countries, that Zhao was freed by the American troops. In this period China also drafted a group of young technicians and capable college graduates to move the nuclear research forward. In spring 1949, newly liberated Beijing did not have the necessary equipment for nuclear research. Minister Li Weihan [2621 4850 3352] of the United Front Work Department under the Communist Central Committee approved a special foreign exchange fund. The money was transferred by Qian Xuesen indirectly to two overseas Chinese students in France and England. With the help of the Curie Laboratory in France and some British friends, they managed to buy a batch of equipment and literature and brought them back to China despite the embargo. This equipment and data, together with the 30 boxes of equipment brought by Zhao Zhongyao from the United States, became the main resources of the Institute of Modern Physics in the early days. Leaders of the Institute led the staff in learning from the Yanan spirit and made the most out of old and discarded equipment. Some of the electronic components were bought in salvage yards and many instruments were built by the researchers themselves. Gradually the research facility was improved and some results were obtained. With Zhao Zhongyao in charge, the Institute built a 700-kV atmospheric electrostatic accelerator and a high-voltage 2.5-MeV electrostatic accelerator. With He Zehui [0149 3419 1979] in charge, the Institute built a number of nuclear detectors and instruments. With Wang Ganchang as the designer, the Institute also built a 30 x 30 x 10 cm^3 7000-Gauss cloud chamber. On Luoxueshan in Yunnan, they built China's first mountain cosmic ray laboratory at an elevation of 3,180 meters and began research on strange particles. Peng Huanwu and others initiated research on nuclear physics, elementary particle physics, and reactor theory. Researchers in the radiation chemistry group began the extraction, purification, and analysis of uranium and the development of heavy water and high purity graphite. By 1955 the Institute of Modern Physics had ongoing research in six areas and had trained a group of key researchers. Some research results were obtained and the foundation of China's nuclear science and technology was established.

In the mid-1950s, when the Central Committee of the Chinese Communist Party promoted the development of atomic energy, R&D in nuclear sciencemade new advances. Notably, a 7000-kW experimental heavy water reactor and a 1.2-meter-diameter cyclotron were built in Tuoli, Beijing, and put into operation in September 1958. The construction of the reactor and cyclotron was organized by Liu Wei [0149 0251], administrator of the Architecture and Construction Bureau under the State Construction Commission and guided by Soviet experts, and built by Beijing municipality, the Third Ministry of Machine Building and the Architecture and Engineering Department, in close cooperation. After that, the Atomic Energy Institute (formerly the Institute of Modern Physics) was led by the CAS and the Second Ministry of Machine Building, mostly under the latter. While completing the reactor and the cyclotron, the Atomic Energy Institute also imported laboratory facilities from the Soviet Union for uranium isotope separation by gas diffusion. Instruments developed independently included high-voltage multipliers, crystal spectrometers,

neutron spectrometers, neutron selectors, nanosecond oscilloscopes, and a zero-power reactor. A total of 50 instruments were built and research began in nuclear physics, reactor physics, plutonium chemistry, and isotope separation. In early 1960, the Institute had a total of 4,300 people, with 1,500 of them being technical staff having a college education. Work began in 20 disciplines and 60 branches. Gradually a comprehensive nuclear science R&D center was formed. it prepared personnel and technology for China's independent development of a nuclear industry and nuclear weapons.

(2) Building Up a Nuclear Industry

While establishing nuclear science and technology, China also began a survey of uranium resources. Under the leadership of Deputy Minister Liu Jie [0149 2638] of the Ministry of Geology, preparation for the mining of uranium began in February 1954. From June to October 1954, geologists Gao Zhizhang [7559 0037 2627] and others surveyed Haicheng in Liaoning and Fuzhong and Shanmuchong in Guangxi, where uranium was discovered before the New China. They brought back uranium ore samples from Shanmuchong. These findings received the attention of Mao Zedong and Zhou Enlai, who were quickly briefed by Liu Jie. Mao said: "We are very hopeful. There are bound to be uranium mines, we only have to look for them."

After accomplishing some preliminary achievements in nuclear technology and making some discovery in uranium mines, the Chinese Communist Party held an expanded meeting of its Central Secretariat on 15 January 1955. In this meeting chaired by Mao Zedong, a policy was formulated to develop China's atomic energy. That decision marked the beginning of China's nuclear industry and nuclear weapons development. On 20 January an agreement was signed by China and the Soviet Union to conduct a joint survey of uranium deposits in China. In April, the State Council decided to establish a Third Bureau of the Ministry of Geology under the Third Office of the State Council. Lei Rongtian [7191 2837 1131] was named bureau chief in charge of all geological efforts related to uranium mines in China. Also, uranium geological survey teams such as the Hunan 309 team and the Xinjiang 519 team were formed with people drafted from relevant departments, regions and armed services in China. The draft orders came from the Party Central Committee, the State Council, and the Central Military Commission. Under the organization of the Third Bureau of the Ministry of Geology and the advice of the Soviet experts, the geological survey teams found a large number of radiation anomalies, including 11 sites worthy of further investigation. The survey effort and industrial evaluation continued and the first uranium reserve data were reported to the state. By 1960, there were eight mining sites for uranium and the first set of uranium mining requirements was satisfied.

As China was planning its first batch of uranium mines, processing plants and nuclear fuel plants, it was faced with a question: how largeshould the nuclear industry be? In early 1957, Zhou Enlai pointed out that China should have its own nuclear industry system and its own nuclear force; however, the problem was to go from "have not" to "have" so the scale should not be too large. Based on this, the Third Ministry of Machine Building re-evaluated the plan in the China-Soviet agreement and felt that the scale of the plan was too big. After repeated studies and to satisfy the requirement of maintaining a complete set of nuclear industry, they proposed a smaller but complete plan. The size of the uranium concentration plant was greatly reduced and investment was reduced by 40 percent. The new proposal suited the Chinese situation better and was approved by the Party Central Committee and the State Council.

Another important issue in China's nuclear industrial development was how to implement the policy of "mainly self-reliant, but strive for external assistance." In the 1959 movement of technological innovation and revolution, some people wanted to improve the technology by revising the Soviet plant design and the design of instruments and meters. Minister Song Renqiong [1345 01717 4522] reported this situation to Mao Zedong in a letter. Mao's comment was "Let us learn how to walk before we learn how to run." Based on this, the Second Ministry of Machine Building urged all the technical workers to patiently learn from the Soviet experts and to understand the Soviet technology. It was emphasized that no revisions were permitted before mastering the Soviet technology, and equipment and instruments supplied by the Soviet Union were not to be modified or dismantled. In cases where the Soviet technology did not suit the Chinese situation, necessary improvements were made only after experimental research and with the approval of the Soviet experts. The State Council also decided that when equipment and raw materials could be found in China, they should be supplied domestically. An effort was made to produce special equipment in China, thus creating the ability to design and manufacture the needed equipment. The construction of the Atomic Energy Institute was accelerated and special research organizations for uranium mine geology and uranium ore refining were established. The initiative of the research personnel was fully mobilized and self-reliance was enhanced.

In the nationwide "Great Leap Forward" movement, there were instances of pushing safety and quality aside in the pursuit of production and construction schedules. For such behavior the Second Ministry of Machine Building took a firm stand and clearly sided with quality and safety. Construction not meeting quality standards had to be bulldozed and rebuilt. Deputy minister in charge of capital construction, Liu Wei, indeed led the destruction of substandard buildings and started construction all over again. This rigorous attitude got the attention of the construction units and ensured the quality of construction.

In the build-up of the nuclear industry, China properly handled the issues of self-reliance, outside assistance, construction scope, and national resources. The correct

policy and practice led to very good results. In August 1960, uranium mines in Chenxian County and Hengshan Dapu in Hunan, and Shengyao in Jiangxi were near completion, the uranium processing plant in Hengyang, Hunan, began installing equipment, the Lanzhou uranium enrichment plant was partially equipped, and the associated civil construction for the atomic enterprise in Qiuchuan, Gansu, and the fuel element plant in Baotou, Inner Mongolia, were also near completion. The successful build-up of the nuclear industry made the development of nuclear weapons possible.

Section 2. Development of the First Atomic Bomb

To speed up the pace of nuclear weapon development, China actively sought help from the Soviet Union. The "Agreement on New DefenseTechnology" signed by China and the Soviet Union contained an article stating that the Soviet Union would help China develop its nuclear weapons. The implementation of this agreement was relatively smooth in the beginning and contributed to the construction of nuclear weapons development bases in northwest China; however, as the split between the two parties and the two countries deepened, the government of the Soviet Union not only ceased to provide teaching models and graphical data for the atomic bomb, but also unilaterally voided the agreement. In August 1960 the Soviet Union withdrew all 233 experts assisting China's development of the nuclear industry and carried away important graphs and data. The supply of equipment and materials stopped shortly thereafter. The unilateral action by the Soviet Union to tear up the agreement caused severe difficulty and great loss in China's nuclear industry and nuclear weapon development. At this key moment, the Party Central Committee decided to develop the atomic bomb with China's own resources. This important policy stimulated the patriotic fervor and national pride of the development personnel. They were determined to develop the atomic bomb with their own intelligence and skill. They were determined to break the hegemonies nuclear monopoly and bring glory to China and its people.

(1) Tackling Key Problems in Atomic Bomb Development

At the end of the 1950s, China's nuclear bases in the Northwest were still under construction and not ready to begin R&D work. The Second Ministry of Machine Building decided to begin the research and design of the atomic bomb in the Nuclear Weapons Institute established in Beijing in July 1958. Efforts were put in three areas. The first area was the assembly of talent. At the end of 1959 nuclear physicist Zhu Guangya [2612 0342 0068] left the Atomic Energy Institute and became the deputy director of the Nuclear Weapons Institute, where he assisted Li Jue [2621 6030] and Wu Jilin [0702 7139 7207] in organizing and coordinating the effort. In March 1960, with the approval of Deng Xiaoping, 105 senior and middle-level technical staff including Guo Yonghuai [6753 3057 2037], Cheng Kaijia [4453 7030 3946], Chen Nengkuan [7115 5174 1401], and Long Wenguang [7893 2429 0342] were drafted to join the atomic bomb development. Subsequently, renowned scientists Wang Ganchang, Peng Huanwu, and Guo Yonghuai took the assignment of deputy director of the Nuclear Weapons Institute. Together with Deng Jiaxian [6772 4471 0341] who came over from the Atomic Energy Institute earlier, they formed the backbone of the nuclear weapons development effort. The second area was the establishment of research laboratories and shops for theoretical physics, explosion physics, neutron physics, radiation chemistry, metals physics, detonation control and ballistic trajectory. The third area was the building of more laboratories and the acquisition of more equipment from other departments and from abroad. After 6 months of preparation the development of an atomic bomb formally began in spring 1960. The atomic bomb was a new topic for China, and initial exploration was conducted in theoretical design, explosion physics, neutron physics, radiation chemistry, detonation control system, and structural design.

(A) Theoretical Design

Theoretical design of China's first atomic bomb was conducted under the supervision of Peng Huanwu, Deng Jiaxian, and Zhou Guangzhao. Peng analyzed the entire process of atomic bomb explosion and determined the principal physical quantities for the different stages. His analysis was very important for understanding the basic principles and the physical picture of the nuclear reaction.

Research proceeded before the nuclear reaction. After the Chinese new year in 1960, Hu Side [5170 1835 1795] and three other young workersstudied the equation of state of the explosion products, particularly the uranium equation of state. They were determined to succeed and began with learning basic knowledge. They surveyed foreign literature and learned as they proceeded. After half a year, they finally established the equation of state for the entire pressure range. These results formed the basis for calculating the overall mechanics of the atomic bomb.

In April 1960, Sun Qinghe [1327 3237 3109], Zhu Jianshi [2612 1696 1102], and eight other young workers performed the whole-body mechanical calculation of the atomic bomb using only a few manually cranked and electric calculators. Because of the large volume of calculations, they worked around the clock in three shifts; everybody worked more than 10 hours a day. Within a year's time, they had repeated the calculation for the material movement within the bomb body a total of nine times, with results very close to each other. In May 1961, Zhou Guangzhao was transferred to assume the duties of first deputy director of the theoretical design office of the Nuclear Weapons Institute. He carefully analyzed the calculation results and proved their correctness from a theoretical approach. Meanwhile, mathematician Zhou Yulin [0719 3022 7792] also obtained the same results using effective computation

procedures. After this work, scientists gained a deeper understanding of the mechanical process before the nuclear reaction. This understanding later became the solid foundation for theoretical design and mechanical calculations of the atomic bomb.

Research was done to study the process after the nuclear reaction. Peng Huanwu described the energy release in the chain reaction and other physical phenomena when the nuclear material was compressed to a super- high critical state. Mathematicians Qin Yuanxun [4440 0337 8113] and Li Deyuan [2621 1795 0337] completed the total calculation for the energy release process after the nuclear material was compressed to a super- high critical state. After 2 years of extensive calculations and repeated discussion, the theoretical designers had a better understanding of the reaction process and performance of an atomic bomb loaded with enriched uranium. The first theoretical design proposal was submitted in March 1963.

(B) Explosion Physics Research

This work was conducted under the supervision of Wang Ganchang and Chen Nengkuan. The goal of the experiment was not only to verify the theoretical design of the atomic bomb and to evaluate the dynamic behavior of the components, but also to solve some key technical problems in the development of the atomic bomb. With the approval of the Central Military Commission and before the completion of the northwest nuclear weapons development base, it was decided that small-scale explosion tests would be conducted at the testing ground of the Army Engineer Corps in Beijing. Tests were conducted to study the detonation element and the equations of state of the materials. The objective was also to investigate the basic principles of atomic bomb design and measurement methods for different parameters, and to train technical personnel with actual operating ability. In early April, the construction of the explosion test site was going at full steam. In order to save time, Wu Yungwen led staff and workers to melt explosives in ordinary kitchen aluminum pots in temporary sheds. Cylinders were formed with cardboard instead of metal molds. Manual stirring replaced mechanical stirring and the first explosive component was cast. Later, they developed a new explosive injection method that improved the quality and performance of the charge. The development of the high-pressure detonator was a cooperative effort by Deputy Director Qian Jin of the Second Laboratory in the Nuclear Weapons Institute, the Beijing Industrial University, the Xi'an Third Academy of the Third Ministry of Machine Building, and the No. 804 Plant. After thousands of tests, a high-performance, high-pressure detonator was developed. Extensive tests proved that performance met requirements. In order to acquire the focused waveform, Chen Nengkuan and coworkers spent about a year in designing and testing the first detonation element. Lin Chuanliu [2651 0278 7511] and coworkers spent 2 years developing electrical measurement instruments and other test instruments. Wu Shifa [0702 0013 3127] applied high-speed photography to detonation experiments and solved the measurement problems in the tests.

(C) Neutron physics and radiation chemistry

This project was led by Qian Sanqiang and guided by He Zehui. The neutron source was an important component of the atomic bomb and its development was assumed by the Atomic Energy Institute and the Nuclear Weapons Institute. The development followed a three-pronged approach. The young technical staff in Wang Fangding's [3769 2455 1353] group conducted hundreds of tests and developed a neutron source at the end of 1962 that met the nuclear weapons requirements. Technicians and workers at the Atomic Energy Institute conquered a series of technological hurdles and solved the packaging problem of the neutron source and the final inspection technique. The neutron source developed by Wang Fangding, et al., functioned successfully in the detonation test of December 1963. It was employed in the first nuclear test. The neutron sources developed by the two other approaches were also successful.

In the area of neutron physics, scientists at the Atomic Energy Institute and other units measured the heavy ion neutron cross section in the fission reaction, the energy spectrum of the fission neutron, and the average number of fission neutrons. They established methods and standards for radiation measurements. The Atomic Energy Institute had also assisted the Nuclear Weapons Institute in completing the theoretical calculation for the fast neutron critical device and the criticality safety calculations.

(D) Detonation control

The synchronous detonation device in the detonation control system was a key component for achieving implosion of the nuclear device. Hui Zhongxi [1920 6988 6932], Zhu Guoliang [4376 0948 2733], and others took on the job with a crude facility and, after several months of hard work, solved the circuit design problem and mastered the design technology for the synchronous detonation device. Meanwhile, other components of the detonation control system were also completed in time. These results were all employed in the first nuclear test.

(E) Structure design

Led by Guo Yonghuai and Long Wenguang, designers of the atomic bomb studied two proposals of the nuclear device from the detonation and mechanics points of view. By 1962 they had obtained the expected results.

(2) Crash Construction of the Northwest Nuclear Weapons Development Base

From March to June 1958, the joint site selection group consisting of Chinese and Soviet experts selected Jinyintan in Haiyan County, Qinghai Province, as the place to construct the northwest nuclear weapons base. The choice was approved by the Party Central Committee in

July. Later, the Soviet Union provided some preliminary designs and a small amount of equipment for part of the northwest nuclear weapons development base. Meanwhile, all regions and departments in China strongly supported theconstruction of the base. The People's Government of Qinghai formed a special group to assist the land use, relocation, road, local construction material, and living supply problems. It also selected 7,000 able-bodied men to participate in the base construction. The construction engineering department selected people from its Lanzhou Engineering Bureau and the Ninth Production Facility Installation Company to form the No. 104 Construction Engineering Company and the Fourth Engineering Office in the No. 103 Installation Engineering Company to assume the construction duties. The Central Military Commission also assigned 1,900 veterans to the base to enhance the capital construction force. This capital construction team moved onto the construction site beginning in February 1959.

In order to save time, design and construction proceeded in parallel. In August 1960, construction started on the detonation experiment site. later, work began on the assembly and explosive processing plant, mechanical processing plant, and standby electric power plant. Construction proceeded at a brisk pace.

However, around 1961, China's national economy encountered some severe difficulties. The situation in Qinghai, harsh even in normal times, became even worse. The monthly grain quota per person was reduced by more than 10 jin; each person could only have two qian of oil and hardly any vegetables. Malnutrition caused edema in more than 40 percent of the personnel in some units. Construction was greatly affected. Faced with this dire situation, base leaders, including Li Jui [2621 6030], strove to keep both the project and the workers' welfare afloat. Teams were organized to work on agriculture, animal husbandry, and fishery. Planting, fishing, and hunting were activities for solving the shortage of staple and supplemental foodstuffs. Zhou Enlai was very concerned about the workers at the base and decided to bring in food from the east and west in order to deal with the emergency. At the worst moment, the Ministry of Food allocated several million jin of soybeans to three units of the Second Ministry of Machine Building in the northwest, including the nuclear weapons development base. The Qinghai People's Government also shipped 40,000 sheep to the base. The Ministry of Commerce set up special second-level wholesale stations in Lanzhou, Gansu. These steps stimulated the confidence and courage of the workers, stabilized the ranks and ensured the normal progress of the project. At the end of 1962, the explosive-pouring plant and two small test sites were completed and the base began to look like a development base. However, the detonation test site and main buildings, like the assembly plant, were yet to be built. In the meantime, large-scale detonation tests and atomic bomb assembly had to be moved from Beijing to the base. These projects required another 100,000 square meters of capital construction. The complexity and quality requirements of the construction, together with the short frost-free period on the Qinghai plateau and under-strength work force made the base construction exceedingly difficult.

In early December 1962, the Central Special Committee reviewed and approved the 2-year plan for atomic bomb development proposed by the Second Ministry of Machine Building. The Committee also investigated the construction progress of the northwest nuclear weapons base and decided to take some action to speed up the pace of construction. On 7 December, Deputy Director Zheng Hantao [6774 3352 3447] of the Central Special Committee office met with 13 departments including the Ministries of Construction, Transportation, Water Conservancy and Electric Power, Telecommunications, and the Army Corps of Engineers, Railways, and Communications. It was decided that a 15,000-man construction team, with 500 pieces of construction equipment and 300 motor vehicles, should be sent to the construction site for a crash building effort. Under the joint command headed by Li Jue, the major construction tasks werecompleted in April 1964, which made the breakthrough in atomic bomb technology possible.

With the completion of the northwest nuclear weapons development base, the development of the atomic bomb was gradually shifted from Beijing to the northwest. Prior to 1969, the Ninth Bureau of the Second Ministry of Machine Building, the Beijing Nuclear Weapons Institute, and the Northwest Nuclear Weapons Development Base were three names of the same institute. The research, design and production of nuclear weapons were done by the same organization. In 1969, the new base was completed and was given the job of nuclear weapons research and design. It was called the Nuclear Weapons Design Institute. The Northwest Nuclear Weapons Development Base was then responsible only for the production of nuclear weapons. The research, design and production of the nuclear weapons have since been separated.

(3) Production of Enriched Uranium and Development of Nuclear Component

(A) Production of enriched uranium

China's first atomic bomb was loaded with enriched uranium. The timely production of acceptable uranium was therefore key to the successful development of the atomic bomb.

Planning of the Lanzhou enriched uranium plant began in 1956 and construction began in 1958. Under the organization of plant director Wang Jiefu [3769 0094 4395] and with help from the No. 101 Construction Company, the Second Engineering Office of the No. 103 Installation Company, and the Atomic Energy Institute, the principal civil engineering was basically completed in 1960. In 1961, the diffusion units were in place and fluoridized. However, production and stable operation of the plant still required uranium hexafluoride material and separation membranes.

To solve the production and supply problem of uranium hexafluoride, Zhou Enlai wrote a letter to Khrushchev in May 1960. Zhou asked the Soviet Union to honor the agreement and provide the Lanzhou enriched uranium plant with the necessary uranium hexafluoride. Because the Soviet Union refused to supply the material, the Second Ministry of Machine Building decided in July 1960 to produce the material by the tube method. Deng Zuoqing [6772 0146 0615] and Zheng Qiongying [6774 8825 5391] of the Beijing Uranium Refining Institute organized an effort to complete the tube production facility in 4 months. The facility produced good-quality UO_2 and UF_4. Meanwhile the effort of Cao Benxi [2580 2609 3588], Wu Zhengkai [0702 1767 6963], and Huang Changqing [7806 2490 1987] of the Atomic Energy Institute built two production facilities of UF_6 using the method; acceptable products were delivered before 1963. Together with part of the UF_6 produced by the recovery facility of the chemical plant at the Lanzhou enriched uranium plant, the needs of the early phase of the enriched uranium plant were satisfied. This simple production facility made vital contributions to the development of the first atomic bomb and to the successful detonation. From 1962 to 1963, under the organization of the Mining Bureau Director Su Hua [5685 5478], the uranium mines at Chen Xian and Hengshan Dapu in Hunan Province and Shangrao in Jiangxi Province and the uranium water processing plant in Hengyang, Hunan, were all completed and placed in service. Acceptable products also began to come from the UF_4 shop at the Baotou Fuel Element Plant and from the UF_6 plant of the Jiuquan Atomic Energy Joint Enterprise. The supply of necessary material to the Lanzhou enriched uranium plant had a reliable source.

The uranium separation membrane represented a sensitive frontier technology and was a highly guarded secret in countries that had it. In the late 1950s, China spent about 4 years and came up with its first generation uranium separation membrane. The effort was organized and coordinated by Zhao Erlu, Qian Sanqiang, and Pei Yusheng [5952 7183 3932] and the work was done by the Ministry of Metallurgical Industry, the Second Ministry of Machine Building, the Chinese Academy of Sciences, the Ministry of Textile Industry, and some plants in Shanghai. This product kept the Lanzhou uranium enrichment plant in stable operation.

On 9 April 1963, under the direction of experts such as Wang Chengshu [3769 2110 2579], Wu Zhengkai, and Qian Gaojun [6929 4108 7301], the Lanzhou plant started its diffusers in batches. On 14 January 1964, it obtained highly enriched uranium suitable for atomic bombs. This achievement was praised and congratulated by Mao Zedong and Zhou Enlai.

(B) Development of Nuclear Components

In November 1961, before the nuclear component plant was built at the Jiuquan Atomic Energy Joint Enterprise, personnel from the enterprise and the Nuclear Weapons Institute built a simple laboratory in Beijing to study the machining of the enriched uranium. Chen Hongyi [7115 1347 3015], He Wenzhao [0149 2429 6856], Yang Yun [2799 1661], and Xu Jiqian [1776 1015 0051] worked for more than 2 years and acquired the technology to cast, machine, and inspect the uranium. They determined the parameters, developed the procedure and the basic principle for impurity control, and laid a foundation for the fabrication of nuclear components.

Construction of the nuclear component plant in the Jiuquan Atomic Energy Joint Enterprise began in August 1959. In the second half of 1962, a design modification proposed by Zhu Linfang [4376 7792 5364] was adopted and the simple nuclear component shop was built in less than a year. From November 1963 to April 1964, chemical engineering and refining of nuclear components proceeded smoothly, but gas porosity in casting remained an unsolved problem and severely affected the quality of the components. The technology for eliminating the porosity was finally found by Zhang Tongxing [1728 0681 2502], under the guidance of Chief Engineer Jiang Shengjie of the joint enterprise and Chief Engineer Zhang Peilin [1728 3099 7207] of the Production Bureau of the Second Ministry of Machine Building. With the skillful shaping and machining by machinist Yuan Gongpu [0626 0361 3184], the first set of acceptable enriched uranium components was produced on 1 May 1964.

In the meantime, the Baotou nuclear component plant, under the supervision of Zhang Cheng [1728 6134], worked for more than 2 years and developed the machining technique for natural uranium components. Acceptable parts were first produced in 1964. By then, all the components needed for the first atomic bomb were produced in time.

(4) Overall Breakthroughs in Atomic Bomb Technology

In spring 1963, scientists of the design, testing, and production departments in the Beijing Nuclear Weapons Institute gradually moved to the northwest nuclear weapons base. The Central Special Committee approved the drafting of 126 senior and middle-level scientists and technical staff to the Qinghai plateau. These included Professors Zhang Xingqian [1728 5281 6870] and Fang Zhengzhi [2455 2973 4249], and Engineer Huang Guoguang. Leading cadres Li Jue, Zhao Jinpu, and Guo Yinghui let the scientists live in the only buildings and moved themselves into tents. Using crude shops, scientists launched into all-out experimental research of the atomic bomb.

Under the guidance of Wang Ganchang and Chen Nengkuan, a series of planned local decomposition detonation tests were conducted from May to November 1963. On 24 December a scaled-down integrated detonation test was performed. However, there were different interpretations of the test results. After Tang Xiaowei [0781 1321 1218] made an overall analysis of the test parameters, a correct judgement was made,

which was later verified by further tests. This integrated test verified the theoretical design and the results of separate tests. It laid the foundation for the design of the atomic bomb.

The success of the integrated detonation experiment and the acquisition of the highly enriched uranium were important achievements in China's development of its first atomic bomb. It indicated that major technical hurdles have been overcome. After receiving the reports, Zhou Enlai happily congratulated the workers for completing vital production and technical tests ahead of schedule. He also encouraged them to be prudent and persistent in carrying out the remaining tasks.

In order to be absolutely sure, scientists conducted a full-scale detonation simulation test and other related tests in June 1964. The tests were a total success. In 4 years, there was a total of 1,000 small-scale tests and several large-scale tests to evaluate the components separately and in combination. The theoretical design was verified and key technical problems in integrated detonation were solved. The results were very fruitful.

Large-scale detonation tests showed that both structural components were satisfactory. To ensure timely production of the necessary components for the first nuclear explosion, Leu Jie held extensive discussions with the experts and technical staff. He decided on 23 March 1964 that a structural component designed by Wu Daixian [0124 0108 0341] with greater rigidity and strength would be used. However, the new component was more difficult to machine to high precision. The required machining precision was not available at that time at either the northwest base or in the Second Ministry of Machine Building. With the permission of the Central Special Committee, a precision machine shop was set up in the 403 Plant of the Third Ministry of Machine Building and the task was completed as an emergency measure. The task was coordinated by Minister Sun Zhiyuan of the Third Ministry, Deputy Secretary Liu Boluo [0149 2672 5012] of the Office of Defense Industries, and Deputy Bureau Chief Lai Jian [6351 1017].

From May to July 1964, scientists at the nuclear weapons base performed vibration tests and transport simulation for nuclear components, explosive components, detonation elements and synchronization devices. Tests results showed that the nuclear components and control systems could stand the transport environment and their structures were reliable. Using a self-developed subcritical device, Lai Zuwu [6351 4371 2976] successfully performed a subcritical test on the nuclear device. His test results showed that all the steps in the assembly procedure of the atomic bomb had sufficient subcritical safety; safety would be ensured even under the least favorable conditions. Using crude testing methods, Song Guangzhou [1345 0342 3166] and others led the workers through a series of tests and solved technical problems in the machining and assembly process. Machining quality of the parts was assured.

In July and August, technical staff and workers at the northwest nuclear weapons base completed the assembly of three acceptable nuclear devices. This was accomplished with strong support from various departments and the operation was performed strictly according to the procedures. The work was led by Cai Baozhen [5591 2128 4176]. In mid and late August, the devices were shipped via special train to the nuclear test base in the northwest. Following the instruction from Zhou Enlai, the movementwas kept under strict secrecy and security. Before the train started, detailed transportation procedures were formulated. Specific requirements were set for the stops along the way and for transfer, teaming, and security procedures. The train was escorted by armed police and the route was guarded by public security police. At the border of two provinces, the train was escorted across the border by the public security chiefs of the two provinces and the security duty was transferred from one to the other. All the steel hammers for rail inspection were replaced with brass hammers to avoid sparks. All the coal used by the train was sifted to detect the presence of explosives. High-voltage power was temporarily cut off in regions where the train was passing. Under tight security and planning, the nuclear devices were safely delivered to the intended station in Xinjiang. The devices were then transported by truck to the northwest nuclear test site. Enriched uranium components were flown directly to the test site.

On 16 October 1964, China's first atomic bomb was successfully detonated at the northwest nuclear test site. After the explosion, the Atomic Energy Institute conducted radiation chemistry analysis and the Nuclear Weapons Institute and the Northwest Nuclear Technology Institute conducted optical and mechanical measurements to determine the power of the explosion. The power was equivalent to 20,000 tons of TNT, close to the theoretical value. The test results showed that the research, design, experimentation, fabrication, and testing of China's first atomic bomb had met the designed requirements and a solid foundation was established for the development of nuclear weapons.

Section 3. Breakthrough in Hydrogen Bomb Technology

As a nuclear weapon, the hydrogen bomb makes use of the enormous amount of energy released at the instance of the fusion reaction (thermonuclear reaction) of deuterium and tritium, isotopes of hydrogen. The power of a hydrogen bomb is much greater than that of an atomic bomb. There is a qualitative jump from the atomic bomb to the hydrogen bomb. All countries engaged in nuclear weapons development have strived to develop the hydrogen bomb as quickly as possible after they succeeded in developing the atomic bomb. China also began its exploration of the hydrogen bomb—and obtained some results—while it was developing the atomic bomb. In February 1965 the Central Special Committee approved the "Report on the Accelerated Development of Nuclear Weapons" submitted by the Second Ministry

of Machine Building and decided to conduct a nuclear test of a hydrogen bomb device in 1968. This goal stimulated all the workers in nuclear science and technology to reach a new high.

(1) Exploring the Theory of H-bomb Design

The success story in China's development of the atomic bomb was the attention to design research and the basic principles. It was also an important approach to the H-bomb technology breakthrough. The Second Ministry and the Nuclear Weapons Institute took some effective actions in basic research.

(A) In December 1960, based on the plan made by Liu Jie, Qian Sanqiong, and organized by Huang Zuchia [7806 4371 3174] and Yu Min [0060 2404] of the Atomic Energy Institute and formed the lepton nuclear theory group. The group began to explore H-bomb principles and the different physical processes and viable structures. In 4 years the group has submitted 69 research result reports and gained in depth understanding of many basic phenomena. In September 1963, some of the scientists of the Nuclear Weapons Institute began the theoretical exploration of the H-bomb by designing an atomic bomb that contained thermonuclear material. After the success of the first nuclear test, the Institute quickly shifted most of the theoretical researchers to H-bomb research. In order tostrengthen the theoretical effort on the H-bomb, the Second Ministry of Machine Building decided to move Huang Zuqia, Yu Min, and another 29 people from the Atomic Energy Institute to the Nuclear Weapons Institute in January 1965. After these changes, the theoretical group became a strong force in H-bomb research.

(B) Formulating design principles.

In February 1965, under the supervision of Zhu Guangya and Peng Huanwu, Deng Jiaxian, and Zhou Guangzhao led the scientists in consolidating the experience of the previous stage of research and formulated a work plan to achieve the H-bomb technology breakthrough. The second step was to complete the theoretical design of the thermonuclear warhead to meet requirements in weight, power, and the deployment of nuclear weapons.

(C) Preparing accurate and complete nuclear data.

Accurate and complete nuclear data are important to the design of nuclear devices. Scientists at the Nuclear Weapons Institute discovered many inconsistencies in nuclear data in the literature. In February 1965 He Zehui of the Atomic Energy Institute led 30 research staff to conduct nuclear reaction cross section measurements for thermonuclear material. They used the research results obtained by Ding Dazhao and others and obtained reliable experimental data after half a year of experimental research.

(D) Conducting exploratory H-bomb test

To understand thermonuclear reaction and to obtain first-hand information as needed in the H-bomb design, the Central Special Committee approved the test of an enhanced atomic bomb. The design of the enhanced atomic bomb was based on the first experimental atomic bomb but contained a certain amount of thermonuclear material; the structure was modified correspondingly. Theoretical design proceeded quickly and used only about half a year. Since the new test used components of the detonation system that was employed in the two previous atomic bomb tests, the fabrication process also progressed quickly. From September 1965 to April 1966, detonation, subcritical, and environmental tests were completed. On 9 May 1966, an atmospheric test of the enhanced atomic bomb was successfully conducted. This test provided real data for the theoretical study of the H-bomb.

(E) Break through the H-bomb design

After a year of investigation, scientists clearly recognized that, in order to break through the H-bomb design principle, they must pursue many approaches and understand the principal factors that affected the burning of the thermonuclear material and the rule of energy release. From February to July 1965, the theoretical department of the Nuclear Weapons Institute concentrated on several structural proposals and conducted repeated calculations. The results were not satisfactory. Facing an impasse, scientists consolidated experience and conducted various special topics symposia and discussions so that everyone could think about the problem and come up with new concepts, new ideas, and new proposals. The main direction for pursuing the H-bomb theory was determined this way.

In the summer of 1965, scientists at the Nuclear Weapons Institute learned from foreign news media that France planned to conduct a test of their first thermonuclear device in 1968. To win one for China and the Chinese people, they proposed to realize China's first H-bomb before the French. Deputy director Yu Min of the theoretical department of the Institute led staff members to the Huadong Computation Institute in Shanghai before National Day and spent all the holidays calculating models. After analysis, they obtained important results in the burning rule of thermonuclear material. However, the model was too heavy and the specific power and specific fusion were low and did not meet the criterion of 1 million tons of TNT for every ton. Yu Min summarized the results and made a series of reports. Staff members calculated some more ideal models and discovered the key in sustained burning of thermonuclear material. This important issue in the H-bomb principle was thus resolved.

(2) Speeding Up the Production of Thermonuclear Materials and the Development of Thermonuclear Components

Another important step in the development of the H-bomb was the production of thermonuclear materials and thermonuclear components.

Just as China was about to install its first lithium deuteride-6 production line, the Soviet Union cut off aid to China. The Second Ministry of Machine Building immediately transferred the scientists engaged in light isotope separation in the Atomic Energy Institute to the Baotou Nuclear Fuel Element Plant to solve technical problems. With assistance from the Atomic Energy Institute, Beijing University, and Qinghua University, plant personnel tackled 95 topics centered on the production of thermonuclear materials and solved the problem of the exchange tower enrichment process and the production rate of the chemical exchange system. Meanwhile, the First Ministry of Machine Building actively sought out production equipment like the reagent pump of the Shenyang Water Pump Plant and electrolysis trough, and satisfied the needs of the lithium deuteride-6 production line installation. The installation personnel actively developed installation tools, modified the installation method, and completed the installation of the main unit in early 1963.

In spring 1963, the lithium deuteride-6 production line was ready for a test run. The intermediate test for heavy water—the material for producing deuterium—had basically been acceptable, but industrial-scale production of heavy water was still not possible. The Central Special Committee requested the Ministry of Chemical Industry to include the project at an earlier date. In July the Committee again studied the heavy water problem and decided that the Ministry of Chemical Industry should give top priority to small shops for producing heavy water. The Ministry then organized Dalian Grease Chemical Plant and Shanghai Institute of Chemical Engineering and accelerated the process of producing heavy water by electrolytic exchange. Acceptable heavy water was produced in December 1963 and in May 1964; there was therefore a technology base for building a heavy water plant. Subsequently the Jilin Chemical Industrial Company quickly built a small heavy water production shop and produced the first batch of acceptable heavy water with strong support from the Beijing Institute of Chemical Design, the First Ministry of Machine Building, and other departments. In this period the test-run of the lithium deuteride-6 production line succeeded on the first try and produced its first batch of products. The plant then acquired the ability to produce lithium chloride and metallic lithium, and produced deuterium by electrolytically decomposing heavy water. On 11 September 1965, the plant synthesized its first charge of lithium deuteride-6.

The Northwest Nuclear Weapons Development Base was responsible for machining lithium-deuteride-6 into thermonuclear material components for the H-bomb according to the design shape and size. In early 1965 Song Jiashu [1345 1367 2885] and other scientists began the R&D of thermonuclear components. The first problem they encountered was the machining of the thermonuclear material. They took a three-prongedapproach to break through the technology. After repeated tests they settled on a fabrication method that could yield near-theoretical density blanks with fewer defects at a lower pressure. Scientists and workers were very conscious about safety in their work: they properly handled the possible ignition problem of the thermonuclear materials during mechanical processing. They also tested dozens of coatings and finally found one coating that helped the short-term storage problem of thermonuclear components. After almost a year of development, the first set of acceptable lithium deuteride-6 component was produced and the fuel problem for the enhanced atomic bomb and H-bomb test was solved. These results were very crucial for the successful development of the H- bomb.

(3) The First Hydrogen Bomb Successfully Developed

In December 1965, experts of the Northwest Nuclear Weapons Institute conducted a series of studies. These studies were chaired by Deputy Director Wu Jilin [0702 7139 7207] and participated in by deputy ministers Leu Xiyao [0149 6007 1031] and Li Jue of the Second Ministry of Machine Building, and Second Bureau Chief Hu Ruexia [5170 5387 3838] of the Defense Science Commission. After these studies, it was determined that the theoretical proposal of triggering the H-bomb with the atomic bomb was reasonable and feasible according to the basic principles. Based on this analysis, it was possible to have a smaller and lighter 1-megaton H-bomb with a higher specific fusion at the end of 1967 or the first half of 1968. The emphasis for breaking through the H-bomb technology was therefore placed on the new proposal. However, the new proposal was only a concept and its success was not ensured; on the other hand, the originally planned H-bomb, although larger, heavier, and having a smaller specific fusion ratio, was more likely to succeed based on theoretical considerations. For this reason, research and testing of the original design was not abandoned either. With the two-pronged approach as the guiding concept, the Second Ministry of Machine Building formulated the 1966 and 1967 plans for nuclear weapons development; the plans were approved by the Central Special Committee. After that, the Committee approved the specific steps to implement the 2-year plan and the request by the relevant departments to cooperate. The new arrangement for breaking through the H-bomb technology developed quickly.

In the new plan, the difficult task of triggering the thermonuclear device with the atomic bomb had to be overcome. After hundreds of detonation simulation experiments and many in-depth academic discussions, a clever method employed by Chen Changyi and Tao Zucong [7118 4371 5115] solved this technical problem and provided experimental data for the theoretical design of the detonator

To design the body of the H-bomb, physicists and mechanics researchers studied the physical picture and mechanisms in the explosion process of the thermonuclear device, investigated the effects of the explosion of the detonator bomb on the main H-bomb, and mastered

the layout of the components and the relationship of energy release. The theoretical design of the H-bomb body was thus formulated.

However, by the time the theoretical design plan for the entire experimental device was handed to the design and manufacture departments, it was already mid-October 1966. The design and manufacture departments had very little time to complete the engineering design and to fabricate the device. Furthermore, the device was very complex, with many odd-shaped components which were hard to make. To ensure quality and schedule, theorists, designers and manufacturers worked together, exchanged ideas, discussed problems, and moved the design and manufacture preparation forward. After the completion of the theoreticaldesign plan, the design and manufacture moved forward together to save time. By December 1966, all the design and manufacturing tasks had been completed. However, when scientists inspected the H-bomb experimental device on 10 October, a major component was found to have quality problems. When Zhou Enlai learned of this, he sent Lie Jie to fly in on a special plane on the next day to inspect the problem. On-site inspection showed a crack that was visible only with a magnifying glass. Liu studied with the scientists and determined that the component was usable and the crack would not affect the explosion test. Thus, the experimental device was shipped to the northwest testing site as scheduled.

To ensure the success of the test, theoretical designers and testing personnel added many monitors for different parts of the thermonuclear device. Eight additional near-field physical measurements were added and each measurement involved many items. Under the guidance of Wang Ganchang and deputy director Hu Renyu of the experimental department, test personnel carefully formulated measurement procedures and repeatedly calibrated and tuned the detectors, transmission system, and recorders. All measurement preparations were ready on time. On 28 December 1966, the design principle test passed with flying colors. The results showed that China had mastered the key technologies of H-bomb development. However, the thermonuclear reaction of this test was incomplete because of the small quantity of thermonuclear fuel used in the test and because of the field limitations of the equivalence. In order to understand the parameters of a fully developed thermonuclear reaction and to further evaluate the design principle and its future prospects, the Second Ministry obtained permission from the Central Special Committee to conduct a direct full-equivalence air-drop H-bomb test. Preparations for this test were to be completed by 20 June 1967. To this end, Mao Zedong signed a telegram authorizing the nuclear weapons base to temporarily halt the "Big Four" activities of the "Great Cultural Revolution." The decision by Mao and by the Central Special Committee was vital to the research, production, quality, and security of the H-bomb development. Close cooperation in theory, experiment, design, and production on the base accelerated the progress and made full use of the facility for developing a thermonuclear bomb and certain other products. On 5 June 1967, the H-bomb for the official test was finished. The various components and subsystems of the H-bomb were inspected for quality before leaving the plant.

A full-equivalence H-bomb test was carried out on 7 June 1967 at the northwest nuclear testing site and the test was a success. The explosive power was equivalent to 3 million tons of TNT.

The reduced-equivalence and full-equivalence H-bomb tests showed that China had mastered the H-bomb technology and was capable of producing H- bombs. This was the second major breakthrough in China's nuclear weapons development and was the basis for developing a system of ballistic missiles and missile-equipped troops.

Section 4. Atomic Bomb and Hydrogen Bomb Reach Application Stage; Research on a New Generation of Nuclear Weapons

The application of the atomic bomb and the H-bomb involved converting the experimental nuclear device into a weapon according to certain tactical and technical requirements. It took extensive engineering research and testing to implement the application.

In June 1963 the Central Special Committee decided that the weapons production problem after the first nuclear test must be solved. In January, the Central Special Committee stated in a report to the Party Central Committee and Mao Zedong that China should systematicallydevelop atomic and hydrogen bombs that could be delivered by missile and aircraft. Thanks to the definitive guidance thoughts in nuclear weapons development and the hard work of weapons developers and nuclear fuel producers, the progress was relatively smooth and the Central Special Committee's requests were met either in time or ahead of schedule.

(1) Atomic Bomb Reaches Application Stage

(A) Airdropped Atomic Bomb

The airborne atomic bomb consisted of the nuclear device, the detonation system, and the bomb shell. It was closely integrated with the delivery aircraft.

China's first nuclear device was originally designed for atmospheric explosion. Under the guidance of Guo Yonghuai, scientists in the Nuclear Weapons Institute began the design in April 1960 and designed three aerodynamic profiles for the bomb shell. With the assistance of the Fifth Academy of the Ministry of Defense and the Beijing Aeronautical Institute, they conducted a number of low- and high-speed wind tunnel tests and made preliminary decisions on the exterior profile and resistance coefficient. They have also produced a scaled air-drop model and tested it in October and November of 1961 above the northwest integrated missile testing

base. The air-drop test of a full-size model was conducted late 1962. Based on test results, an aerodynamic profile was finalized and, based on this profile, structural design and fabrication of the bomb shell proceeded.

After the mode of testing for the first nuclear device was changed to a tower explosion, research on the air-drop atomic bomb continued. In 1963 the Nuclear Weapons Institute collaborated with a unit in the Air Force to conduct flight tests for the detonation control system. After a number of improvements, the detonation control system was completed by the Nuclear Weapons Institute in early 1965.

After China's first successful nuclear test, scientists at the Nuclear Weapons Institute improved upon the theoretical model of the nuclear device based on the tactical and technical requirements of air-dropped bombs and raised the reliability of the structure. Led by Shu Songgui [3990 2646 2710] and Yu Daguang [0205 1129 0342], designers completed the design of the remote sensing system in 3 months. The model bomb for practicing air drops and the bomb for "cold" experiments and live tests were completed respectively at the end of March and April at the Northwest Nuclear Weapons Development Base. Large-scale vibration, temperature, and simulated environmental tests showed that the structure was reliable and the detonation system and remote sensing system both functioned normally.

An air-drop atomic bomb test, approved by the Central Special Committee and held on 14 May 1965, was successfully conducted. The explosive power was basically in agreement with the theoretical design.

From the first nuclear test to the first air-drop nuclear test, only 8 months elapsed. This indicated that China's development of atomic weapons had proceeded very quickly.

(B) Nuclear Missile Warheads

The Nuclear Weapons Institute followed the policy set by the Central Special Committee that "nuclear weapons research should be based primarily on missile warheads and only supplemented by air-dropped bombs," and began developing atomic bomb missile warheads. Some of the scientists still working on the development of the first atomic bombwere transferred to work on missile warheads.

Theoretical research of missile warheads began in August 1963. Based on the design of China's first atomic bomb and the tactical requirements of medium-range and short-range surface-to-surface missiles, scientists worked on miniaturization design and combined detonation test results and feasibility of the fabrication process. Corresponding measures taken in the structural design reduced the size and weight of the warhead, increasing its rigidity to meet the needs of a varying environment in the flight of a missile.

After the reduction in size, scientists made extensive calculations to address the waveform symmetry problem of the explosion. At the end of 1965, they provided acceptable detonators for the missile warhead and ensured the synchronous nature of the composite waveform.

The warhead experienced vibration, impact, high and low temperatures, and acceleration during the storage phase and in flight. To ensure normal functioning of the warhead under these conditions, scientists at the Nuclear Weapons Institute designed a safety device for the detonation system and reliable trigger and self-destruct systems. If the missile launch failed, the nuclear warhead would not lead to a nuclear explosion. Scientists conducted a series of tests and verifications. First, certain key components of the detonation system of the nuclear device and the entire system were given centrifuge, vibration, impact, and extreme-temperature tests. Next, they went beyond the limitation of simulated transport of the model bomb and boldly tested high-speed transport of the nuclear warhead at 40 kilometers per hour. In 1966, they conducted detonation tests that simulated the actual environment and the enlarged graphpaper error. These tests helped finalize the model of the device. To test the detonation control system for the warhead; they also conducted "cold" runs without the nuclear material. Test results showed that the detonation control system was properly designed. To ensure absolute safety, the Nuclear Weapons Institute of the Second Ministry of Machine Building followed Zhou Enlai's instruction and conducted combustion tests that simulated the situation of a nuclear warhead with the safety still engaged and simulated drop impact tests. These tests showed that the nuclear warhead was safe and reliable. After the successful completion of the above tests, a nuclear missile was successfully launched on 27 October 1966. This proved that China had acquired battle-ready nuclear missiles.

(2) Production of Plutonium and Tritium

In China's nuclear weapons development the first nuclear material used was enriched uranium-235 and thermonuclear material lithium deuteride-6. To improve the quality, increase the power and reduce the weight of nuclear weapons, China urgently needed to produce plutonium and tritium.

Plutonium-239 does not exist in nature. It is produced by irradiating U-238 in a reactor. China's first graphite light water reactor for producing Pu-239 began its construction in March 1960. When the Soviet Union withdrew its aid, the project was brought to a stop, but construction resumed in June 1962. After 4 years, the Baotou nuclear fuel element plant produced acceptable fuel elements. The Shanghai Turbine Works of the First Ministry of Machine Building and dozens of other plants produced 154 components for the reactor. Under the direction of Zhou Zhi [0719 4442] and Jiang Shengjie, the Jiuchuan Atomic Energy Consortium, the 102 Company, and the third engineering office of the 103 Company jointly

overcame technical hurdles in construction and production, and completed the production reactor in October 1966. The reactor was officially put into service in 1967.

The post-processing plant of the Jiuchuan Atomic Energy Consortium was responsible for processing the fuel element after irradiation. The plant developed an innovative extraction method that replaced the precipitation method provided by the Soviets. The method was developed with the cooperation of the Design Institute of the Second Ministry of Machine Building, the Atomic Energy Institute, and Qinghua University. The new method saved costs and reduced construction time. In May 1965, construction began on the experimental facility of the post-processing plant. With rush building by the fifth engineering office of the 103 Company, the plant was finished in September 1968 and put into service to produce Pu-239. A large-scale post-processing plant was built in April 1970. China's tritium production facility was built without any outside help. The Atomic Energy Institute completed the study of tritium production in the 1960s. In the mid-1960s, the Second Ministry of Machine Building's design institute completed a design for a tritium production line. In May 1968, the tritium production line was officially put into service to produce acceptable tritium.

The completion of the Pu-239 and tritium production facilities provided important materials for improving the performance of nuclear weapons.

(3) Hydrogen Bomb Reaches Application Stage

The development of the air-dropped nuclear bomb and nuclear missile warhead and the breakthrough in hydrogen bomb technology were the foundation for making the hydrogen bomb a weapon. However, while work was proceeding following the instruction of the Central Special Committee, the "Great Cultural Revolution" took place. In October 1969 the Lin Biao [2651 1753] counter-revolutionary clique interfered directly. Many senior and mid-level scientists engaged in nuclear weapons research and cadres at the office and shop level were criticized and persecuted; research and experimentation could not proceed normally. After the Lin Biao counter-revolutionary group was crushed, many victims were rehabilitated thanks to Zhou Enlai's personal attention.

Beginning in 1967, the Defense Science Commission and the Office of Defense Industries have held many meetings with R&D units for missiles and nuclear weapons to discuss the tactical and technical targets of thermonuclear warheads. These targets were officially approved by the State Council and Central Military Commission before they were handed down. To make the thermonuclear warhead more compact, lighter, reliable and easier to use, scientists and researchers engaged in nuclear device research and the development of detonation control and remote sensing systems branched out into other areas. These areas included new structures, new technologies, new materials and new designs, detonation control system reliability, environmental adaptability, miniaturization design, explosive power reliability, experimental techniques to evaluate the flight of the nuclear device, more advanced, multifunction large facilities, and ground testing facilities. These efforts led to expected results and moved the application of the hydrogen bomb forward.

To satisfy the tactical requirements for the weapons, researchers also developed large-scale explosion tests, mechanical tests, environmental tests. and flight tests for weapon components and detonation control systems in the missile warhead. Through these tests, the design was evaluated and the components were checked. Test results served as a data base for improving thermonuclear warheads. To evaluate the explosion performance of the nuclear device, researchers also followed Zhou Enlai's request and tested the flight of the nuclear device using nonnuclear means. The test they used was not only safe and economical, but also met the requirement of evaluating the nuclear device.

The application of the hydrogen bomb proceeded according to the instruction of Zhou Enlai. Testing and design finalization was donesimultaneously and small-scale production began after the design was finalized. After the completion of the nuclear device evaluation, scientists at the Nuclear Weapons Design Institute proceeded with the test production using the design drawings and technical documents. After acceptable products could be produced, the final weapons development report was submitted. Drawings of the final design, technical papers, and engineering data were submitted to the State Design Finalization Committee for evaluation and approval. Batch production of the weapons began after the design was approved. This procedure was followed in the 1970s and 1980s for the development of a medium-range missile, medium-to-long range missile, ICBM, and submarine-to-surface missile and associated warheads. The designs of these weapons were finalized and the weapons were placed into service.

(4) Research on New Generation of Weapons

Scientists at the Nuclear Weapons Design Institute followed the new direction of smaller, mobile, safe, and reliable nuclear weapons. They conducted extensive preparatory research in related disciplines and technologies. They explored new design theories and manufacturing techniques and launched into the development of a new generation of nuclear weapons. Under the leadership of the Office of Defense Industries and the Second Ministry of Machine Building, the Nuclear Weapons Design Institute cooperated with the Northwest Nuclear Testing Base and conducted a series of experiments from 1982 to 1988. The design principle was checked, breakthroughs were made in key technologies, and China's nuclear weapons research entered a new era.

China made the decision to develop nuclear weapons in the mid-1950s. In the last 30 years, China has established a complete nuclear science and technology industrial

system, cultivated a formidable power, accumulated rich experience, and built a high-level R&D team. They independently developed atomic and hydrogen bombs and put them into military service. They also made major achievements in the research of new nuclear weapons. They have made great contributions to China's defense construction and broke the nuclear threat and nuclear blackmail by the superpowers. They have done a great deal in elevating China's international stature. However, there were also failures and set-backs in China's nuclear weapons development. Due to insufficient understanding of the scientific principles, some nuclear tests did not reach the expected goals. shall continue to develop nuclear technology and to maintain an effective defense nuclear force for the purpose of national defense and world peace.

Chapter VII. Testing of Nuclear Weapons

A nuclear weapons testing is the explosion experiment of a nuclear device conducted under present conditions and based on military needs and scientific research goals. It is indispensable to the development of nuclear weapons. China began building its nuclear test sites in 1958. By 1989, China had conducted 34 nuclear tests using different test methods and at different power. These tests provided important basis for the research and improvement of nuclear weapons and for the design, production, and application of nuclear weapons. They contributed greatly to the enhancement of China's defense power.

Section 1. Establishment of Nuclear Test Base

(1) Surveying, Siting and Setting Up of Test Base

In April 1958, the Central Military Commission decided to build a nuclear test site (later known as the Nuclear Test Base) and assigned army engineers the job of surveying, siting, designing, and constructing the test base. A nuclear test team was formed based on part of the cadres and soldiers of the Shangqiu Infantry School. This team was first responsible for surveying and constructing the base, and then was given the duty of conducting the nuclear tests. In May, the siting committee, headed by Commander Chen Shiju [7115 1102 2829] of the engineer troops, studied the relevant information and followed the siting criteria recommended by the Soviet experts. After the paper study, four possible sites were selected, including the region west of Dunhuang in Gansu, and the region north of Lop Nur in Xinjiang. The region west of Dunhuang seemed to be more appropriate. In June, Chen Shiju [7115 1102 2829] led 30 people in a detailed survey of the region west of Dunhuang. The region 160 km west of Dunhuang was chosen to be the central experimental zone. This location was also the Soviet experts' choice, but the experts pointed out that in finalizing the central zone location, high-altitude weather data must be acquired. They recommended that a permanent weather station be established. In July, Chief of Staff Huang Kecheng [7806 0344 6134] obtained the approval of Peng Dehuai to build the nuclear testing ground.

In August 1958, the Ministry of Defense appointed Zhang Yunyu [1728 5686 6877] to be director of the nuclear test team (later the title was changed to Nuclear Test Base Commander), Chang Yong [1603 0516] to head the political committee, and Zhang Zhishan [1728 1807 0810] to be deputy director (later changed to Deputy Commander of the Nuclear Test Base). For 2 months, an expedition of 1,800 people consisting of the nuclear test team, the topographical drafting team of the chief of staff, the geological survey team of the Ministry of Metallurgical Industry and the engineer troops, led by Zhang Zhishan and Chang Yong, completed the topographical survey, engineering geology, and hydrological geology survey. The survey was completed on 20 August. Subsequently, an engineering siting group completed a siting survey. The group consisted of people from the Defense Engineering Design Institute of the Engineers, the Fourth Institute of Design of the First Ministry of Machine Building, the Barracks Management Department of the General Logistics Service, and communications troops. In early November, Chen Shiju and Soviet geologists made an on-site review of the engineering siting survey results. Chen also led the research to determine the relative layout of the experimental central zone and the auxiliary zones. In the study, the high-altitude wind direction was found to be likely from the northwest to the southeast, but the wind direction on the surface was mostly from the northeast to the southwest. Under such wind directions, the effects of the radioactive materials from the nuclear test still awaited the study by the Soviet experts. In early November, after Zhang Yunyu assumed his duties, he carefully surveyed the construction zone and studied the detailed organization of the nuclear test team with Chang Yong and Zhang Zhishan. After the Soviet experts went home, they analyzed the weather data of the border area and determined that the high-altitude wind direction at the chosen central experimental zone was from the northwest to the southeast, with the Dunhuang region smack in the downwind direction. On 21 November 1958, the Soviet Union recommended to China by letter that the feasibility of moving the nuclear test site to the Lop Nur region in Xinjiang should be considered. Chen Shiju and Wan Yi [8001 3015] led a study of the Soviet letter and organized further investigation of the relevant weather data. They proved that the high-altitude wind direction in the Dunhuang region was from the northwest to the southeast. In order to protect the residents of the Dunhuang region, Chen Shiyu and Wan Yi obtained permission from the Central Military Commission and sent Zhang Yunyu, Zhang Zhishan and Shi Guohua [0670 0948 5478] to lead a survey team for a site survey in the Lop Nur region. From late 1958 to early 1959, they surveyed the topographical and geomorphological features, water resources, and soil quality of the region and selected an area northwest of Lop Nur as a suitable test site. In early January, Wan Yi was briefed by Zhang Yunyu and made an aerial survey of Lop Nur region. Wan concurred that the region northwest of Lop Nur was suitable for a test site. On 6 February, in a report submitted to Huang Kecheng, Wan Yi proposed that the

nuclear test field be built in the region northwest of Lop Nur. The reasons were that the predominant wind direction at high altitude in the Lop Nur area was westerly, there were no residents within 450 km in the downwind direction, and there were no significant settlements within a radius of 230 km. Water was readily available for construction and for subsistence, and there was strong support from the Xinjiang Autonomous Region. The Central Military Commission agreed to move the test site from Dunhuang region to the Lop Nur region. The Commission notified Wang Enmao, Sai Fuding [6357 4395 7844] and the Xinjiang Military Region on 12 March and asked for leadership and support. Beginning on 1 April, the survey group led by Zhang Yunyu conducted survey and siting for the technical zone, the office and living quarters zone, the airport, the communications facility and roads in the region west of Lop Nur. This siting survey was participated in by the Engineering Troops Headquarters, the Corps of Engineers, Defense Engineering and Design Institute, the general logistics barracks management department, Military Medicine Institute, Air Force construction department, communications troops, the Fourth Design Institute of the First Ministry of Machine Building, and the survey company of the First Ministry. People in the survey team worked around the clock and, in only 11 days, selected the site proposals for the various zones and the associated construction. On 4 May, the headquarters of the Engineers submitted a nuclear test site survey report to Peng Dehuai and Huang Kecheng. This report was approved by the Central Military Commission on 15 May.

Concurrent with the siting survey, the organization of the nuclear test team was also being worked on. In November 1958, Zhang Yunyu submitted the organization plan to the Ministry of Defense. To facilitate the staffing of the team and the planning of future work, Wan Yi submitted a draft organization plan to Huang Kecheng, Yang Chengwu and Zhang Aiping on 7 January 1959 and suggested that the plan be adopted for trial use. The plan was approved by Huang Kecheng on 10 January. The General Political Department picked cadres with sound political and military training for the nuclear test team from the services, military schools, and the various military regions. The General Staff Headquarters dispatched troops from Shenyang, Beijing, and Jinan military regions to the nuclear test site. By the end of May the nuclear test team was basically established. South of where the troops were stationed was a prairie with malan flowers in full bloom. At the suggestion of Zhang Yunyu, the office and living quarters was named Malan, for the hardy flower that survived and bloomed in the desert.

(2) Overcoming Difficulties in Building the Test Base

In mid-June 1959, the Nuclear Test Base held its first expanded meeting, chaired by the Party Secretary Chang Yong of the base. The meeting reviewed the survey and siting effort of the previous 10 months and decided that the main mission for the second half of 1959 was to focus on the construction preparation and getting ready for the ground-breaking in 1960; at the same time, the ideology style of the troops was improved and organizational and vocational work was carried out.

On 27 November, the Communist Party Central Secretariat listened to the briefing of the Central Military Commission regarding the siting of the test base and the construction progress of the base. The Secretariat approved the construction plan and requested that the base be built as soon as possible.

To accelerate the base construction, the Ministry of Defense decided to assign the engineering construction mission to the Special Engineering Command (SEC) of the Engineers. The Xinjiang Military Region assigned 2,200 new soldiers to the base. The SEC assigned four engineer battalions and one vehicle battalion to base construction. A construction team of more than 30,000 people was formed from the above units and the following units: Lanzhou No. 2 Construction Company, the Tianjin Construction Company, and the construction brigade of the Second Division of the Xinjiang Production Construction Army Group. In addition, the No. 273 hospital in Guangzhou Military Region was transferred to the nuclear test base to serve the construction workers.

On 1 April 1960, under the leadership of the SEC, the base construction began. The major construction projects were road construction from the living quarters to the experimental center zone and the command control zone, establishing communications lines, building a landing strip, barracks, power plant, and associated facilities.

Two major difficulties were encountered soon after the beginning of construction. First, the Soviet Union tore up the agreement and halted its aid so the designs and equipment specified in the agreement were not forthcoming. Faced with this difficulty, Zhang Aiping followed the instruction from Nie Rongzhen and immediately organized army units to work on the engineering design and construction of the base. The Defense Engineering Design Institute of the engineer troops used the preliminary Soviet design as a reference and began a technical design that suited the Chinese situation. The Signal Corps, the Engineers Command and the Nuclear Test Base jointly conducted communications and control tests between the control zone and the experimental central zone. Chief Hu Ruoxia of the second bureau of the Defense Science Commission organized relevant engineering and technical personnel and evaluated the designs of the test zone. The relevant personnel came from the Defense Engineering Design Institute of the Engineers, the communications troops of the General Staff Headquarters, and technical staff at the Nuclear Test Base and the 9th Bureau of the Second Ministry of Machine Building.

To ascertain the utility and specifications of the special equipment and to organize development and production, the Defense Science Commission formed a leading

group headed by Zhang Yunyu. After a few months, an inventory was made for the equipment of known utility and specification. But there remained some key measurement equipment whose test methods and measurement functions would have to wait until after results were obtained in the atomic bomb development. For this reason, the construction design of the Nuclear Test Base was still not available at the end of 1962.

The second difficulty encountered in the base construction was that China happened to be in a period of financial difficulty. There was a shortage of investment, construction materials, construction machinery and associated tools, labor force, and transport vehicles. The Defense Science Commission asked the base to recognize the national difficulty and make do with available resources. The base scaled down some of the capital construction and the construction troops did everything possible to overcome obstacles and get the job done. To combat the lack of vehicles, one commander of an engineer regiment carried rocks for road construction on his back. Without enough mechanical tools, the troops fixed and fashioned tools by hand. One engineer regiment did not have a large crane to build their plant, so they made a hoist themselves and moved 11-ton concrete structural members. There were not enough steamrollers, so reinforced concrete rollers were pulled by men to compact the road base. To keep the supply of materials, equipment, and living necessities flowing, people in charge of logistics were out hustling. Transport was difficult on the Gobi Desert. Grain had to be hauled from Nanjiang, 1,700 km away, and the round trip took one month. Transporting the large amount of material used for constructing the base was a formidable task. Drivers drove fully loaded trucks through deserts, mountains, and windy passes. Local workers participating in the construction were fearless and cooperated fully with the troops. By the end of 1962, 564 km of roads had been built in the experimental zone and where the troops were stationed. Barracks and plant buildings exceeded 100,000 square meters. A simple airport had been built and 1,800 km of communications line had been set up for communications within the base and between the base and Urumqi and Beijing. The nuclear test base was taking shape.

Section 2. Explosion Test of the First Atomic Bomb

On 16 October 1964, China successfully exploded its first atomic bomb, thus erecting a milestone on the road of China's development of nuclear weapons.

(1) Preparing for the Test

On 3 November 1962, Mao Zedong approved the target date of 1964 for China's first test of an atomic bomb. After that the Defense Science Commission met many times to discuss preparations for the various tests. On 21 November, the Defense Science Commission proposed that the armed services be responsible for the construction of the ground tower experiment site, communications engineering, and protective missions such as aviation, security, weather, geodesic survey, and mapping. The proposal was approved by Nie Rongzhen and Luo Ruiqing. On 25 December, Zhang Aiping and Liu Xiyao chaired a nuclear test preparation meeting. In the meeting assignments were given to the Air Force, Headquarters' units, signal troops, chemical defense troops, equipment planning units, weather bureaus, mapping bureaus, and the General Political and Security Department. It was decided that a command protection working group consisting of the leading cadres of the units attending the meeting should be formed. The group leader was Base Commander Zhang Ying. Following the meeting, special task teams were formed to prepare for the nuclear test.

(A) Establishing Research Institutes and Preparing for Experimental Technology

In October 1962, the Defense Science Commission proposed and obtained approval to form a Nuclear Weapons Experiment Institute based on the technology foundation of the Nuclear Test Base. A cadre of 20 technical staff was selected from the Second Ministry of Machine Building and other units. In early November, the Second Ministry assigned Deputy Director Cheng Kaijia of the Nuclear Weapons Institute and Director of Technology Zhang Chao [1728 6389] of the Nuclear Test Base to be jointly responsible for the building of the Nuclear Weapons Experiment Institute. Zhang was assigned the deputy position and Cheng Kaijia was the deputy director. Forty key technical personnel were selected by the Organization Department of the Communist Party Central Committee, the General Political Department, and the Defense Science Commission. These people included Lu Min [0712 2404], Lu Zuying [7120 4371 5593], Xin Xianjie [1823 6343 2638], Dong Shoushen [5516 1108 5450], Sun Ruifan [1327 3843 5603], and Wang Ruzhi [3769 5423 5347]. One hundred fifty college graduates were selected from military engineering schools and other schools to work in this new institute. With these personnel, the institute took its initial form.

The spirit was to proceed with building the institute and to prepare for the nuclear test at the same time. The work plan (draft) for testing the first atomic bomb and urgent research topics were proposed on 26 November 1962 by Cheng Kaijia, Lu Min, Lu Zuying, and Xin Xianjie. The proposal was based on the preliminary recommendations by the Ninth Bureau of the Second Ministry of Machine Building. After half a year of hard work, 83 topics were proposed by May 1963; 80 percent of the technical problems required outside collaboration. Deputy Secretary Zhang Zhenhuan [1728 7201 1403] of the Defense Science Commission and Bureau Chief Hu Ruogu [5170 5387 0858] organized the collaboration with 23 units including the Chinese Academy of Sciences, plants and institutes in relevant ministries, and research institutes in the armed services. Assignments

were taken by the Changchun Institute of Optics and Fine Mechanics of the Chinese Academy of Sciences, Xi'an Institute of Optics and Fine Mechanics, Institute of Physics, Institute of Geophysics, Institute of Electronics, Institute of Automation, Institute of Mechanics, Atomic Energy Institute of the Second Ministry of Machine Building, laboratories No. 19 and No. 10 of the Tenth Academy of the Ministry of Defense, the Military Engineering School, the Institute of Chemical Weapons, and plants in the First, Fourth, and Fifth Ministries of Machine Building. Special leadership groups were formed, strong technical resources were allocated and superior equipment was acquired to complete the testing and manufacturing missions in time.

To meet the needs of R&D, the Nuclear Weapons Experiment Institute established a technology committee. The main tasks of the committee were to discuss technical proposals, to coordinate research missions, to check the progress periodically, and to solve problems in a timely manner. The base also invited renowned scientists to give talks and held more than 100 technical meetings to carry out extensive discussions of the testing plans.

The Institute made good progress on the technical topics that it assumed. Deputy Director Lu Min of the Nuclear Physics Laboratory, with strong support from the Atomic Energy Institute, developed a complete equipment system for measuring nuclear chain reaction kinetics. Xin Xianjie and others proposed a plan to develop control system instrumentation and worked with Laboratory 19 of the Tenth Academy in developing highly reliable and compatible instruments. Wang Ruzhi was responsible for measuring the nuclear explosion shock wave and explosion equivalence and Sun Ruifan was responsible for measuring the fireball and the radiation. Yang Yusheng was responsible for obtaining samples of the radioactive cloud and conducting radiochemistry analysis. Lu Zuying was responsible for measuring early phase radiation. These leaders have all led the technical staff and obtained good results.

In just a year or so, with strong support of relevant units, the Institute developed more than 1,000 testing, sampling, and control instruments. Each instrument was validated in a simulation explosion and the functions of the instruments were found to be reliable and stable.

(B) Selecting a Surface Nuclear Test Site

From November 1962 to early 1963, the Defense Science Commission had more than once brought together the Nuclear Weapons Institute, the Nuclear Weapons Institute and other research units to study the testing method and testing plan for the first atomic bomb in China. Zhu Guangya and Cheng Kaijia proposed that the atomic bomb first be exploded on a tower to make sure that the action of the core was reliable and then it could be tested in an air burst. The tower test would also facilitate the collection of reliable data. The Defense Science Commission therefore decided that the first atomic bomb test would be done on a tower. The Nuclear Test Base then organized a siting effort for the ground explosion, formulated a layout plan for the test site, and had the Defense Engineering Design Institute design a steel tower. In May 1963, Zhang Aiping reported to the Central Special Committee and the Central Military Commission on the location of the test site and the layout of the site. The Central Special Committee approved the report in July. The Central Special Committee office took care of some of the urgent needs in construction funds, building materials and machining tasks.

The construction of the nuclear test site began around April 1963. The design of the test structure was handled by the Defense Engineering Design Institute of the Engineers. The Institute did not have reference material on most of the items, but managed to carry out research and design simultaneously, with close cooperation from the Nuclear Weapons Institute and the Nuclear Weapons Experiment Institute. Engineers responsible for designing the steel tower and associated facilities were led by Qu Congzhi [2575 1783 3112]. After investigation and discussion, the design was completed at the end of July 1963. The design was reviewed and approved by experts organized by the Defense Science Commission.

The steel tower employed a seamless tube structure with a square cross-section. The associated facilities included a hoist, air conditioning, electric power, ground transportation, and a temperature-controlled suspended basket. The tower was 102 meters high, had 8,467 components and weighed 76 tons. The seamless tubes were made by Anshan Iron & Steel Works as an emergency assignment by the State Economic Council. The frame was built by the Huabei Metal Structures Plant of the Ministry of Construction. The suspended basket and the ground hoist were made by the Beijing Crane Factory. These units all gave the atomic bomb testing a high priority and completed the tasks. All the components for the tower were transported to the experimental zone at the end of February 1964.

The installation of the tower was led by the Special Engineering Technical Team of the Engineers. The precision requirements were stringent and the time schedule was tight. An installation team of 160 people was formed, based on 32 technicians for work high above the ground as the key personnel. These personnel were transferred from the broadcasting bureau and the Lanzhou Chemical Industry Company as requested by the Second Bureau of the Defense Science Commission and assisted by office of the Central Special Committee. Sixty-eight working days were used to complete the construction of validated quality.

Designing of the communications project was assumed by the General Staff Headquarters' Signal Corps. With close cooperation between the design department, user department and the construction unit, and with scientific coordination of the construction tasks, the job was

completed on schedule and the quality met specifications. The engineer regiment responsible for civil construction ignored the summer heat and winter cold, and contributed a great deal to the testing of China's first atomic bomb.

With hard work by all the departments, all 154 projects were completed on schedule at the end of 1964. The quality of the output met the requirements and the results created a favorable condition for the later air burst test.

(C) Test Site Preparation Completed in 3 Months

Test site preparation began in May 1964. The 26 participants of this effort included the General Staff Headquarters of the PLA, the armed services, the military districts of Xinjiang and Lanzhou, the Second Ministry of Machine Building, the public security department, the Tenth Academy of the Ministry of Defense, military engineering schools, institutes of the Chinese Academy of Sciences, and the August-First Movie Producers. A total of 5,058 people worked on the project. Under the unified command of the Defense Science Commission, these units moved into the nuclear test experiment field in an orderly manner.

To organize and direct the experiment, Zhang Yunyu proposed to draw on the experience of combat command and combine this with the unique characteristics of scientific testing. The organization and command of the test site was based on the "Methods for Nuclear Weapons Testing" authored by Zhang Ying.

The test mission was jointly assumed by the 21st team of the Nuclear Test Base, the ninth team of the Second Ministry of Machine Building, and the Atomic Energy Institute. The test items included in the experiment were mechanics, optics, and three types of nuclear measurements. There were 38 items and 992 test points. More than 1,000 pieces of test instruments were used, most of them within a radius of 8 km from ground zero. The wired automated control system for the detonation control and measurement was carefully installed and tuned to eliminate hidden pitfalls. Cadres, experts, and the people worked together with a highly responsible and serious scientific attitude. By mid-August, all the equipment had been installed and tuned up. The technical team gained experience and became familiar with the performance and operation procedures of the instruments; tuning procedures were also perfected.

Weather condition assurance was handled by the weather bureau of the General Staff Headquarters. The Bureau assigned a group of specialists to enhance the weather stations at the nuclear test base; new instruments were installed. In March 1964, the General Staff Headquarters invited the Central Weather Bureau and weather bureaus in various provinces to form a northwest special weather network. Weather conditions for the first atomic bomb test and a weather assurance plan were formulated. In the meantime, the test base also began long-term, mid-term, and short-term weather forecasts at the test base. These forecasts were directed by Deputy Bureau Chief He Gefei [6320 2706 7236] of the Headquarters weather bureau and weather expert Gu Zhenchao [7357 7201 3390] of the Geophysics Institute of the Chinese Academy of Sciences. Weathermen analyzed the accumulated weather data of the test zone and surrounding areas for the last several years. They also investigated the weather pattern of the area in the September-to-December period and got the essence of 3-5-day weather forecast and 48-hour forecasts.

Communications assurance was uniformly organized by the signal troops of the General Staff Headquarters, with strong support from the Ministry of Communications. The Signal Corps installed wired communications circuit and opened back-up wireless station. The communications assurance team of the Nuclear Test Base installed permanent circuits at the test zone, built a radio receiver and transmitter center, telephone stations, carrier stations, booster stations, power stations, and 50 km of insulated wire. Communications were assured between the test zone and various stations and points and particularly between the test zone and Beijing.

Security assurance was led by the chemical defense troops of General Staff Headquarters. The chemical defense troops organized a 670-man safety team to work at the test zone. They jointly formulated safety and security regulations and rules with the Nuclear Test Base. They installed wired and wireless remote dosimeters and built shower stations. Soldiers of the First Battalion of the chemical regiment wore plastic clothing and gas masks and conducted training day after day on the Gobi Desert. The temperature in the protective clothing reached 40°C. The troops perspired several cups of sweat in each hour of training. They lost 1.5 to 2 kg after each training session.

The Air Force was responsible for aviation. The Air Force established a command post at the Nuclear Test Base and used 14 aircraft for transportation, acquiring radioactive samples, dosimetry surveys, weather surveillance, searching the landing points of sample parachutes, and aerial photography. Some of the tasks had to be carried out above contaminated zones. Pilots and test personnel practiced repeatedly and got every movement down pat. The Air Force also dispatched a radar battalion to assure air warning for the test zone surroundings.

Nine military units organized by the Defense Science Commission conducted 21 tests of eight different types to obtain casualty data on humans and objects and to investigate protective measures. Effects on aircraft, tanks, self-propelled guns, artillery, communications equipment, ships, entrenchments, mines, animals, medicine, food, sea water, and oil were tested with the subjects located within a 200- to 300-meter range.

Logistics in the experiment zone was handled by the Nuclear Test Base, with strong support coming from the

General Logistics Department, the Second Material Department, the Military Medicine College, the Second Mobile Field Hospital, and the Ministry of Trade. For shipping material by highway and by rail, a transport group was formed. The group was headed by the military transport department of the General Staff Headquarters and supported by the second material department of the General Logistics Department and the Nuclear Test Base. The Ministry of Railways provided strong support for this effort. Logistics personnel had to deal with long-distance, high-volume transportation from scattered supply points; 1,116 pieces of rolling stock and 1,270 motor vehicles were mobilized to travel more than 18.51 million kilometers to move 33,000 tons of equipment. The transportation group made sure that 200 tons of supplies were delivered daily. Drivers used their leather overcoats to wrap precision instruments, or had back-up drivers hold the instruments on their laps so that the equipment was delivered undamaged to its destination. To provide on-site treatment of illness or injury, medical units organized mobile field hospitals and special rescue teams. The Defense Science Commission published "Temporary regulations on maximum allowable dosage of ionizing radiation."

In the process of preparing for the tests, the public security department and the general political department jointly organized security groups to handle security matters in the tests. In the meantime, security orders were issued and the public was educated about security. Security troops organized by the test base patrolled the perimeter of the site. Soldiers carried 30 to 40 kilograms of weapons, backpacks, rations, and water and patrolled more than 4,000 kilometers in 6 months to ensure the safety of the test zone.

All units participating in the test preparations heeded the request of the general political department and enhanced their ideology effort. Leading cadres and political personnel repeatedly explained the significance of the test to the test personnel to improve their political responsibility and their confidence in accomplishing the mission.

With the strong cooperation and hard work of the units, all test preparations were completed in mid-August.

(2) Organizing Test Rehearsal for Direct Experience

The rehearsal for the first nuclear test was conducted under conditions that approached the real test. All preparation tasks were extensively and systematically evaluated to assure that the first test would be successful. The rehearsal began with the transportation of the atomic bomb. For the on-site dry run, the Northwest Nuclear Weapons Development Base of the Second Ministry of Machine Building specifically produced a simulated atomic bomb. On 10 July 1964, Zhang Zhenhuan called a meeting to discuss the transportation of the atomic bomb. On 14 July, Zhou Enlai pointed that the transport of the simulated atomic bomb had to be done carefully to avoid accidents and each step had to be kept secure and confidential. Zhang Aiping was joined by leaders from the Central Special Committee, the Defense Science Commission, the Second Ministry of Machine Building, the Security Department, the Air Force, and the Military Transportation Department of the General Staff Headquarters on 24 and 25 July to inspect the transport aircraft and the air-conditioned train at Xijiao Airport of Beijing and at the Xizhimen train station, respectively. They studied security measures at the site and made specific arrangements for the combined air and land transportation. Leading cadres and workers of units participating in the transportation meticulously planned and executed the transportation mission of the simulated atomic bomb.

Following the decision of the Central Special Committee, a 68-member first test committee and a 35-member first test party committee were formed to provide unified direction and command of the entire test mission. The committees were made up by leading cadres and experts from the Defense Science Commission, the Second Ministry of Machine Building, the Nuclear Test Base, and the headquarters and armed services. Zhang Aiping was chairman and party secretary of the test committee and Liu Xiyao was deputy chairman and deputy party secretary. Major members were Chang Jun [2052 6874] (deputy commander of the Air Force), Zhang Zhenhuan, Zhang Yunyu, Li Jue, Zhu Guangya, Cheng Kaijia, and Bi Qingtang [3968 1987 1016] (deputy director of the chemical troops of the General Staff Headquarters), and Zhu Qingyun (director of the science and technology department of the General Staff Headquarters).

The on-site dry run was conducted from 26 August to 1 September. The nuclear test committee party secretary put forth a call for "guaranteed detonation, measurement, and security." The rehearsal included bomb assembly, remote detonation, test measurement, dosage surveillance, sample acquisition, and protection and safety. The rehearsal consisted of single task rehearsal and joint rehearsal. Attention was given to the assembly and control of the bomb. In assembling the bomb, workers repeatedly inspected each component and carried out the assembly and tower installation according to the engineering procedures. The control system was tested 53 times. Through the rehearsal, the test preparation was given an extensive and across-the-board inspection; some direct experience was obtained for facing the real test. The nuclear test committee party secretary ordered that "each small problem must be solved and no tests will proceed with unresolved problems." Regulations and procedures were modified according to the approach of defining personnel, job assignment, position, movement, and relationship. Problems in organization and technology were solved one by one. Test procedures and command methods were formulated and a main control station and safe withdrawal and sample recovery commands were established.

(3) First Atomic Bomb Successfully Detonated

On 16 and 17 September 1964, the Central Special Committee was briefed by Zhang Aiping and Liu Xiyao regarding the rehearsal. The timing of the actual test was discussed and an agreement was made to conduct the test in October; Zhou Enlai would report to Mao Zedong and the Party Central Committee about the decision. The test committee held special meetings to discuss countdown standards and timing for emergency abort. The dosage standards and safety protection rules were revised. Preparations were made for smoke and cloud detection outside the test zone, for observing ground settlement, and for emergency evacuation of personnel and residents. Plans were made to respond to premature explosion and errors.

The atomic bomb for the real test was moved to the experimental site on 4 October. Scientists made an overall inspection of all the components and control and measurement systems and found the quality to be within specification. Zhang Aiping, Liu Xiyao and other leaders and experts of the departments personally inspected the assembly of the bomb and the control and measurement systems. On the evening of 8 October, Wang Ganchang, Guo Yonghuai, Peng Huanwu and Deng Jiaxian arrived at the test zone by special plane. Leaders, experts, and the people in participating units worked together, held democratic technology meetings, and made a final check of the tasks following the requests of the test committee.

On 9 October, the test party committee reviewed the weather forecast and recommended that the test be held between 15 October and 20 October. A special envoy was sent to Beijing to report to Zhou Enlai about the preparation and the recommended test time.

At one o'clock in the morning on 11 October, Zhou reviewed the report and had a secretary carrying the report to Mao Zedong, Liu Shaochi [0149 1421 1142], Lin Biao, Peng Zhen, He Long, Nie Rongzhen, and Luo Ruiqing to get their consent and signatures. Zhou then sent a letter to Liu Jie: "Please tell Zhang and Liu that we agree with the arrangement described in their letter to have the test between 15 and 20 October. They may decide the detonation date and time according to the weather conditions and inform us after a decision is made." The test office in Beijing then forwarded Zhou's instruction to the office of the test committee.

After all preparations had been completed, the main factor affecting the detonation time was weather. On 12 October, the weather people forecast a possibility of good weather on the 16th. People in charge of the test committee then studied the weather around the clock with meteorological experts, including Gu Zhenchao, and closely watched the weather for the 16th. At 6 PM on the 14th, Zhang Aiping chaired a party standing committee meeting and analyzed the weather in detail. A decision was then made to fix the formal test on 16 October. At 1830 14 October, the assembled atomic bomb was hoisted to the top of the tower. The test committee office communicated the decision to Zhou Enlai and Luo Ruiqing via the Beijing test office. Zhou approved the decision at 2030 hours.

At 1920, 14 October, the atomic bomb was steadily hoisted to the top of the tower and positioned in the closed workroom. In the morning of the 15th, the test field weather department consulted with the General Staff weather bureau and decided that the good weather expected for the 16th was meeting the test requirements. The test committee decided that 1500 hours on 16 October would be the zero hour. Zhang Aiping and Liu Xiyai then sent a request to Zhou Enlai, Lin Biao, He Long, Hie Rongzhen, and Luo Ruiqing for approval of the time. Zhou immediately approved the choice of time.

After zero hour was approved, the test committee officially issued an order to act according to the previously approved plan. Combat units and the weather bureaus of the General Staff Headquarters, the Defense Industry Office, the Defense Science Commission, and the health department double-checked air defense, radioactive smoke and cloud detection, radioactive dust measurement and monitoring, security and evacuation of key factories, aviation safety and control, and radio communications. The weather department at the test site made weather forecasts every 2 hours.

At 0400 on the 16th, Zhang Aiping and Liu Xiyao made a final inspection of the preparation under the tower and approved that the atomic bomb detonator would be connected at 0630. They then went to the main control station to inspect the readiness of the control system.

Technicians responsible for connecting the detonator, the power source and the probes carefully completed all the steps according to the manual, followed by self-check, mutual check, and check by the leader. At 1030, the tasks were completed, Zhang Yunyu, Li Jue, and Zhu Qingyun evacuated from the tower. Zhang Yunyu then came to the main control station and handed the key to the detonation control panel to Zhang Zhenhuan. At 1430, Zhang Aiping, Liu Xiyao and others entered the Baiyun observation station located 60 kilometers from ground zero. Zhang Aiping then briefed Zhou Enlai on a secure telephone line. Zhou then approved the detonation according to schedule. At 1440, or 20 minutes before zero hour, Zhang Zhenhuan ordered "power on," "turn on," and "warm up" in the main control room. The main operator Han Yunti [7281 0061 2748] accurately pressed the proper buttons and all return signals were normal. Ten seconds before zero hour, Zhang Zhenhuan ordered "start" and Han Yunti pressed the final button. While the programmed automatic control ticked away second by seconds, the announcer called out "10,9,8,7,6,5,4,3,2,1, Detonation!" Suddenly, from the depth of the Gobi came a blinding flash followed by a giant fireball rising from the surface. A hurricane-like shock wave spread from the center and an explosive noise shattered the environment. After that, the fireball turned into a smoke cloud and gradually merged with the

dust column from the earth, forming a spectacular mushroom cloud. Based on the flash, fireball, and mushroom cloud, experts judged that the explosion was a success. Suddenly, all the test personnel let out a triumphant cheer for China's first atomic bomb test. At 1504, Zhang Aiping reported to Zhou Enlai that: "The atomic bomb was exploded on schedule, the mushroom cloud has risen, and the explosion indications show that it was a nuclear explosion. The test has succeeded." Zhou was delighted to hear it and asked people to do well in the work after zero hour and report the test results as soon as possible.

At the test site, post-zero-hour activities proceeded briskly and orderly according to the joint plan and the action plan. One minute after zero hour, the artillery company fired sampling chutes toward the mushroom cloud. Seven minutes after the explosion, the first team in charge of radiation surveillance moved toward the explosion zone, they discovered that the upper half of the steel tower had melted and evaporated and the lower half had collapsed on the ground. The rock and sand on the ground around the tower were melted by the high temperature of the nuclear explosion and had turned into fused glass. One hour later, an IL-12 aircraft flew into the mushroom cloud to take samples. All the participating units skillfully accomplished their tasks.

As planned before zero hour, health and safety organizations in 15 provinces, municipalities, autonomous regions, and cities including Gansu, Beijing, Liaoning, Shanxi, Henan, Jinan, and Qingdao intensified their close monitoring of the background radiation level and their surveillance of the effects of radioactive particulates in the air and on the ground and the arrival times at various locations. The Air Force, the General Staff chemical troops, and the General Staff weather bureaus worked closely and took samples at different locations along the diffusion path of the radioactive cloud in a timely fashion.

Based on preliminary data taken at various test points, the test committee organized experts to make a study. They verified that a nuclear explosion had indeed taken place and the power was estimated to be more than 20,000 tons of TNT equivalent. After that, Zhang Aiping and Liu Xiyao reported the results to Mao Zedong, Zhou Enlai, Lin Biao, He Long, Nie Rongzhen, and Luo Ruiqing. That evening, the Chinese Communist Party Central Committee and the State Council issued a congratulatory telegram to the test committee and to all those who had participated in the test.

When the atomic bomb exploded, 97 percent of the measurement instruments functioned accurately and collected a large amount of data. Missions to survey the dosage, recover articles, and collect smoke samples were completed successfully and all personnel entering the contaminated zone had returned safely. Chemical analysis was made for soil, water, grain and vegetables. Results showed that the radiation dosage in the smoke and cloud trace zone was within the allowable range. Technicians carefully examined damage to objects and recorded the results. Analysis of such data yielded useful experimental data for future radiation effect experiments.

In mid-November, experts and scientists at the Northwest Nuclear Weapons Development Base and the Nuclear Weapons Experiment Institute made a systematic analysis of the test data. After verifying all key data, they concluded that the power of the atomic bomb was 22,000 tons of TNT equivalent, in agreement with the theoretical design. Test results showed that China's first atomic bomb has reached a high level in theoretical design, manufacture and assembly technology, testing method, measurement instruments, and automated control equipment. The test had achieved the expected goals.

Section 3. First Atomic Bomb Airburst Test

On 14 May 1965, China successfully conducted an airburst test of an atomic bomb. This marked the milestone that China was in possession of practical nuclear weapons.

(1) Getting Ready for the Test Before May Day

While organizing the tower test for the atomic bomb, the Defense Science Commission and the office of Defense Industries were also preparing for the airburst test. To satisfy the needs for dropping an atomic bomb, a number of units made a joint study of the technological requirements for modifying the Hong-6 aircraft. These units included the Office of Defense Industries, the Defense Science Commission, Air Force combat units, the engineering units, the Fourth Bureau of the Third Ministry of Machine Building, and the Ninth Bureau of the Second Ministry of Machine Building. In September 1964, the Xi'an Airplane Plant of the Third Ministry of Machine Building completed the modification of the first Hong-6.

In December 1964, the General Staff Headquarters and the Defense Science Commission formulated a plan for the airburst test. They determined that the goal for the airburst test was to verify the technical performance of the atomic bomb under dynamic conditions and to measure its power. Test results would be used as a basis for improving the design. More complete radiation effect tests would also be conducted. They required that all preparation be completed by 1 May 1965. This plan was approved by the Central Special Committee.

After the General Staff Headquarters and the Defense Science Commission jointly issued the test and protection plan, military and non-military units completed various technical preparations. From mid-February 1965, on-site preparations were carried out at the Nuclear Test Base. By 11 April, construction teams of the nuclear test base, the railway troops and the Ministry of Petroleum had completed 351 tasks including installing the target marker and the radar reflectors, and various testing and radiation effect experiments. After 20 days of tense work, equipment installation personnel

had installed 727 pieces of control and measurement instruments and performed 48 tests. Preparations for the comprehensive rehearsal had been completed.

Deputy Commander Cheng Jun oversaw the air practice. Two teams made up by Li Yuanyi [2621 3293 0001] and Yu Fuhai [0060 4395 3189], and Xu Wenhong [1776 2429 1347] and Zhao Chengye [6392 2052 2814] of the Fourth Independent Regiment flew Hong-6s for high altitude optics flight training. By 23 April, they had flown 11 training flights and dropped 29 training bombs over the airburst test zone. They also flew 14 training flights at other Air Force target ranges and achieved the required bombing accuracy. In addition, the Air Force conducted training flights for the sampling plane and for parachute surveillance and radiation surveillance flights.

The General Staff weather bureau led a study of weather analysis. Units participating in the study included Air Force headquarters, the Lanzhou Air Force weather bureau, the Northwest General Missile Test Base, and the weather department of the Nuclear Test Base. The analysis was based on weather trends of the large area, actual observation data of stations in the test zone, and local weather changes. They mastered the basic rules for the appearance, sustainment, and disappearance of good weather days. Using available equipment, they tried everything to monitor weather changes and to improve the forecast accuracy.

The communications department studied the emphases of the various stages and formulated a protection plan. They inspected communications equipment and circuits, and repeatedly practiced the procedure. The General Staff training department organized tactical teams of the armed services and prepared for the tactical exercise under the conditions of a nuclear explosion.

Bombing practice used three models of bombs. The two bombs for the dry run and the two bombs (one spare) for the official test were fully assembled at the Northwest Nuclear Weapons Development Base. Vibration tests showed that they were structurally dependable. The detonation control system and the remote control system functioned normally and met the requirements for air transport and dropping.

In mid-March, Zhang Aiping, Zhang Zhenhuan and others inspected the bombing training and the preparation for the airburst test at the flight training field and the nuclear experimental zone.

On 20 March, the Central Special Committee reviewed the nuclear bomb preparation. Zhou Enlai stressed in the meeting that this test be properly prepared, experience from last test be learned, and arrangements be made more carefully, more thoroughly, and more securely. In a word, all experimental data that should be acquired would be acquired. To test the effects of the explosion, the killing and damage radius in the air, on the ground, and under different conditions had to be determined. China was facing nuclear blackmail and nuclear threat. It did not want to make hundreds of nuclear tests. Our nuclear tests were all based on military and scientific and technological needs and had to be successful on the first test. After the meeting, Zhang Aiping and Zhang Zhenhuan reported the details of the airburst test preparations to the Central Special Committee. Such details included basic tests, effects tests, tactical exercise, surveillance of radioactive smoke and clouds outside the test zone, earthquake, micropressure, and surface radioactive dust measurements. Liu Shaoqi, Deng Xiaoping, and Peng Zhen reviewed the report. Zhou Enlai also talked face-to-face with the standing committee members of the Communist Party Central Political Bureau.

With strong commitment from everyone, it was decided that all preparation before the comprehensive preview should be completed by the first of May.

(2) Integrated Rehearsal and "Practical Demonstration"

On 28 April, a comprehensive rehearsal was conducted following formal procedure. The aircraft piloted by Li Yuanyi and Yu Fuhai dropped the first dry-run bomb at the experimental zone at 8:50 and the bomb exploded on time. The explosion projection point was 96 meters southeast of the target center. The detonation and remote sensing systems worked normally and ground test instruments functioned basically normally. Organization and command and various logistical protection were all accomplished according to plan. After the preview, various units examined the problems revealed in the trial and took corrective action to complete the final preparation. Meanwhile, the Central Special Committee and the Central Military Commission approved a 90-member second nuclear test committee to lead the test. The committee was chaired by Zhang Aiping and had nine vice chairmen, including Liu Xiyao.

On 1 May, the weather department reported the possibility of good weather from the 9th to the 15th. Zhang Aiping and others then recommended to the Central Special Committee and the Central Military Commission that a good day be chosen in that period to conduct the real test. Mao Zedong and Zhou Enlai also approved the recommendation. Zhou stressed that the test must be assured and should not be forced.

On the 7th, leaders of the test committee met with experts and weather forecasters in early morning and at 1400 hours and determined that the weather on the 8th might satisfy requirements, so they recommended that the test be conducted on the 8th. Zhou Enlai and Luo Ruiqing then approved the recommendation. At this time, Zhou had Yang Chengwu and Luo Shunchu work on the readiness, radioactive trace surveillance outside the test site and measurement of ground settlement.

Late at night on the 7th, the test committee again examined the weather. At 2 AM on the 8th, Zhang Aiping spoke to Zhou Enlai on the telephone and recommended that zero hour be set at 8:00; Zhou approved. But at 4:30 on the 8th, weather forecasters found in the sensing information that the high-altitude winds over the test site had shifted from northwest to northeast and test

conditions were not met. Zhang Zhenhuan and Zhang Yunyu then immediately had their people calculate the possible contamination region. Results showed that the test site would be contaminated if the test took place. At 6 AM, Zhang Aiping immediately placed a call to Zhou Enlai to report the situation. Zhou immediately ordered a halt to the test and changed the status to "ready."

Although the test did not take place on the 8th, a general inspection did. It was a practical demonstration more practical than the comprehensive rehearsal. The practical demonstration proved that the preparations had been done well and that the systems could endure the real test. Moreover, it also improved the command experience.

(3) Successful Airburst Test of First Atomic Bomb

During the waiting period, the various units took protective measures for the nuclear bomb projectile, the aircraft, expensive instruments, and specimens. The test committee continued to focus on the weather conditions. After working around the clock for several days, a forecast came at 2:30 on 14 May that there would be a brief period of good weather from 9:00 to 12:00 o'clock on 14 May. The test committee then boldly decided that 9:30 14 May would be zero hour. The decision was reported to Zhou Enlai and Luo Ruiqing and they approved the decision.

The zero hour information was then given to the Air Force command and the Northwest Nuclear Weapons Development Base. Upon receiving the information, they made a final inspection of the assembled atomic bomb and hung it in the bomb bay of the aircraft. Responsible personnel at various levels signed their names. At the test site, the final preparation was completed in only 5 and one-half hours.

At 30 seconds past 8:30, Li Yuanyi and Yu Fuhai took off with the bomb. At 9:26, Yu Fuhai reported seeing the target marker at a distance of 50 km. To ensure accuracy and to make sure that ground instruments and effects test instruments could obtain reliable data, the flight plan called for the plane to enter the target zone three times. After finding the target marker, Yu Fuhai computed the drop and aimed at the target based on aircraft altitude, speed, wind speed, and wind direction. Yu Fuhai flew over the target twice and reported the aiming situation and the computed data to ground command. The command post then ordered the aircraft to make the third entry. The arming switch was turned on at 9:53. At 9:57, the atomic bomb was connected to its power source. At 9:58:40, the automatic bomb release was activated and the atomic bomb was released at 9:59:10. Due to the sudden loss of weight, the plane jerked up, and the atomic bomb was heading straight to the target. At 9:59:38, the atomic bomb exploded in the air above the target marker.

As planned, the Nuclear Weapons Experiment Institute and the artillery effects team immediately made rapid measurements of the nature of the explosion, its altitude, projection point, and power. Preliminary results were reported within 10 minutes: The explosion altitude was about 500 meters, the explosion projection point was about 135 meters from the target center, the azimuth was 232 degrees, and the explosion power was greater than 30,000 tons of TNT equivalent. Zhang Aiping immediately spoke to Zhou Enlai and Luo Ruiqing on the phone and reported the preliminary results. Zhou and Luo were very pleased and congratulated all the people who had participated in the te^t. Zhou also congratulated the bomber crew.

Three minutes after the explosion, the first radiation observation eschelon of the first chemical company of the Nuclear Test Base left its position and moved toward the explosion zone. Twenty minutes after the explosion, a report on the dosage in the contaminated zone was available. Three hours after the explosion, various units followed the plan and systematically recovered numerous items. tactical demonstration teams came through the explosion zone 8 hours after the explosion and gained some understanding of tactical action using atomic explosion effects. There were 3,250 man-times of entry into the contaminated zone and not one person exceeded the allowable dosage standard. By observing the damage situation of the test articles, a limit of the killing power was obtained. All necessary information was obtained in this one test.

Outside the nuclear test site, various departments conducted planned tests and proved that there was very little surface particulate contamination, all dosages were within the allowable range.

To praise and encourage the people who had participated in the development and testing of the nuclear weapons, the Communist Party Central Committee and national leaders Zhou Enlai, Lin Biao, Chen Yi, He Long, Nie Rongzhen, and Luo Ruiqing received the department leaders, scientists, technical experts, and pilots in the Great Hall of the People on 30 May.

Section 4. Test of Missile With Nuclear Warhead

To test a missile with a nuclear warhead, the missile serves as the carrier and a nuclear warhead is delivered to a target location to cause a nuclear explosion. On 27 October 1966, China successfully delivered an atomic bomb with a medium- to short-range missile and conducted a nuclear explosion test. It marked the possession of practical missile warhead weapons by China.

(1) A Careful Decision

On 5 December 1963, the Central Special Committee made a decision that China's nuclear weapons development should be based mainly on missile-delivered warheads supplemented by aircraft-delivered warheads. To link up the atomic bomb technology with the missile technology, technical discussions and coordination were held by scientists and engineers from the Nuclear Weapons Institute of the Second Ministry of Machine Building and the Fifth Academy of the Ministry of

Defense. These activities were organized by the Central Special Committee, the Defense Industries Office, and the Defense Science Commission. R&D efforts were initiated according to technical topic.

Since China had no experience in this area, it had to go through a learning process in evaluating the performance of the missile's atomic warhead. Initially, the Nuclear Weapons Institute believed that an atomic bomb would be ready for installment on a medium- to short-range missile after ground simulation tests for missile flight environment, detonation test, full-range flight test of the detonation control system, and underground tests of the performance of the nuclear warhead. For this reason, the third nuclear test arranged by the Defense Science Commission was an underground test. The purpose was to determine the power and performance parameters of the medium-to short-range missile with an atomic warhead. In November 1965, the Defense Science Commission and the Second Ministry of Machine Building did some in-depth analysis and decided that the underground test could not test whether the atomic bomb would satisfy the actual flight conditions. In order to develop nuclear warheads that could survive the flight test, the underground test was temporarily put on hold; instead, a "cold" test under flight conditions would be conducted. Once there was strong confidence, a "hot" flight test would be made. In terms of actual need, the "hot" flight test would be best conducted at full equivalence and full range so as to test the combination of the atomic bomb and missile technology. On 13 December, the Second Ministry made such a suggestion to the Central Special Committee. At the end of December, Zhou Enlai chaired the Central Special Committee meeting and carefully studied the suggestion. Zhou asked the Defense Science Commission to make up several scenarios and make some comparisons for the Committee to evaluate.

In February 1966, the Defense Science Commission invited leaders from the Second and Seventh Ministries of Machine Building, the General Staff, the Equipment Planning Department, the Northwest General Missile Test Base, and the Nuclear Test Base to study the test proposal of the (modified) medium- to short-range surface-to-surface missile with nuclear warhead. The meeting decided that neither ground simulation tests nor underground explosion tests could truly simulate the actual fight conditions to test the combination of the missile and the atomic bomb. A "cold" flight test could not evaluate the actual condition of the atomic bomb during flight. A full-range, full-power "hot" test with a normal trajectory and a low-altitude explosion would not only achieve the test goal but would also conform to actual war conditions. In terms of reliability and test safety, the (modified) medium- to short-range missile had its own self-destruction device. If a malfunction occurred during the powered part of the flight, a signal could be sent from the ground to destroy the missile. The nuclear warhead had a safety switch and the switch would not open if the warhead fell off during flight. The bomb body would be destroyed upon impacting the ground but there would not be a nuclear fission reaction. So the "hot" test was feasible from a safety point of view. It was therefore decided that a "cold" test would be made as a practice run, followed by a "hot" test. In the meeting, specific studies were also made for the launch site, the target zone, the range, the explosion altitude, the test items, and the division of tasks. On 26 February, the Defense Science Commission reported the study results to the Central Special Committee.

On 11 March, Zhou Enlai chaired a Central Special Committee meeting and carefully studied the Defense Science Commission report. Based on the technology level at the time, and the desire to quickly develop and test a missile warhead, the Central Special Committee agreed to the test plan proposed by the Defense Science Commission. The Committee asked the Science Commission to organize the Second and Seventh Ministries and conduct more preparatory tests so that the test could be guaranteed absolutely safe. The commission also set a date of the end of August for completing all preparatory tests.

(2) Careful Preparation

In order to guarantee the absolute safety of the "hot" flight test of the nuclear warhead missile, the Defense Science Commission, the Office of Defense Industries, and the Second and Seventh Ministries of Machine Building made careful preparations. In March and June 1966, the Defense Science Commission twice reviewed the technical plan, launch plan, measurement plan, and accident handling plan and set a progress schedule for field engineering, weather, communications, aviation, and logistical tasks. Meanwhile, special topics studies and arrangements were also made for the political work of the test mission. The Office of Defense Industries also called a number of meetings of the Second and Seventh Ministries to study the development and test of the missile and warhead. Problems that arose in the coordination were resolved in a timely manner.

The Nuclear Weapons Institute of the Second Ministry of Machine Building conducted a series of tests for the nuclear device and the detonation control system. It also revisited the reliability of the detonation system and the self-destruction system and concluded that reliability was assured. Plants and institutes of the Seventh Ministry of Machine Building completed the production mission on schedule and maintained high quality. They also conducted self-destruction tests of the bomb and proved that the safety system functioned reliably.

The Northwest General Missile Test Base proposed a launch plan, selected the launch position, built a temporary launch pad, underground control and command rooms and personnel shielding structures, and began operation practice. The nuclear test base selected the target zone, built rudimentary roads to the target zone, constructed measurement stations, proposed measurement plan, and made arrangements to measure the explosion position and explosion power. The two bases

respectively formulated safety measures for the launch position and the target zone.

On 30 June, on his way back to Beijing from an overseas trip, Zhou Enlai stopped by the Northwest General Missile Test Base, viewed the launch test for the medium- to short-range missile and inspected the preparation for the nuclear weapons test.

On 5 September, Nie Rongzhen was briefed by the Defense Science Commission and leaders of participating units, and inspected the completion of the preparation. On the 12th, Zhang Zhenhuan led some workers to the two bases to inspect the preparation, and put the test plan and safety measures on a solid basis. On the 15th, the General Political Department approved the formation of a party committee for the "missile-bomb" test. Zhang Zhenhuan was named the first deputy secretary and Li Zaishan [2698 0375 1472] and Zhang Yunyu were the deputy secretaries. From 24 to 29 September, the launch zone and the target zone conducted a number of time-synchronized logistical communications and signal exchanges and joint launch practices. Through these practices, the operators became familiar with procedure-and-command relationship, and actually checked the test facilities, control systems, wired and wireless communications systems and circuits in the target zone. Inaccurate call-out by commanding personnel, sluggish hand operation, and malfunctions of individual instruments were corrected.

On 25 September, Zhou Enlai again chaired the Central Special Committee meeting and in principle approved the arrangement of the Defense Science Commission to conduct joint self-destruct tests in October, "cold" flight tests in mid-October, and to determine the date for the "hot" test based on the results of the above two tests. The Central Special Committee also ordered the Defense Science Commission to form a joint group for unified command to temporarily evacuate the 10,000 residents under the flight path of the missile.

At the end of September, the missiles and warheads used for the self-destruct tests and for the "cold" flight tests arrived at the Northwest General Missile Test Base. Testing at the base and communications during the test, weather, aviation, medical care, protection and smoke, and cloud detection outside the test site had all been properly handled. The safety of the residents was put on a solid basis.

To ensure that the "hot" flight of the combination test was failure-proof, a combination flight test was conducted at the Northwest General Missile Test Base on 7 October to evaluate the safety self-destruct system. After the launch, all the instruments on the missile and on the ground functioned normally. Following the planned procedure, trajectory and timing, the warhead was first destroyed in the air, followed by the destruction of the missile body. The target zone also went through a normal procedure exercise. The test results showed that the missile functioned normally and the safety self-destruct system was reliable. The goals of the test had been achieved.

On 8 October, Zhou Enlai chaired a Central Special Committee meeting and heard Zhang Zhenhuan's report on the combination test, the self-destruction experiment, and the preparation for the "cold" and "hot" flight tests. Zhou was also briefed on the weather forecast for October. Zhou pointed out that since the test was to be conducted on land, there could be no accidents. The "cold" test had to be carefully inspected; the "hot" had to be even more carefully monitored. Every step had to be 100-percent problem-free. The nuclear warhead had to go through impact tests, including oblique impact and lateral impact. The warhead had to be guaranteed not to explode under various anomalous conditions. The "cold" flight was scheduled around the 15th. Test results had to be submitted within 2 or 3 days so that Chairman Mao could make up his mind. Zhou assigned Zhang Zhenhuan to be responsible for this test.

At 8:33 on 13 October, the first "cold" test missile was successfully launched. At 1730 on the 16th, a second "cold" test missile was launched. Loaded with simulated warheads, these two missiles made normal flights, the detonation control systems worked reliably, and the explosive components were detonated at the planned altitude above the target zone. The reliability of the missile and the detonation control system was again verified. In these two "cold" tests, all formal procedures and steps were executed in the launch zone and the target zone. The tests served as overall checks for all the preparatory work.

(3) Combination Test

On 12 October, Zhou Enlai called a special meeting and, together with Nie Rongzhen, Ye Jianying, and Yang Chengwu, was briefed by Zhang Zhenhuan about details of the launch zone inspection and target zone preparation. Joined by leaders of the relevant departments and experts, they again made an across-the-board review of the test preparation and safety issues. Ye pointed out that the success of that test would attract great attention in China. The "hot" test was the final test and everything had to be checked carefully, including every screw, and human error had to be eliminated. Zhou stressed that the test must be fail safe and assigned Nie Rongzhen to take charge of the launch.

Nie arrived at the Northwest General Missile Test Base on 25 October and heard a briefing on the testing situation of the missile and the warhead. He inspected the test preparation and relayed Mao Zedong's instructions given in the previous evening when Mao heard Nie's briefing. Mao said that the upcoming test could succeed or fail, but it would not matter even if it failed. Nie took Mao's comment to mean that people should prepare for the worst but do their best to succeed. Nie asked the leading cadres to carry out Mao's instruction and carefully execute the final preparations.

At 1600 hours, the test committee studied the weather forecast for the next 48 hours in the launch zone and the target zone. It was deep autumn weather and the wind was strong at the launch zone. The forecast was that weather would improve after daybreak on the 26th. Nie agreed with the opinion of the test committee that the formal launch should be scheduled for the 27th.

At the launch site, the testing team carefully completed all tests for the missile and made sure that all the technical specifications were met. Scientists of the Northwest Nuclear Weapons Development Base repeatedly and rigorously inspected and tested each component. With assistance from scientists of the First Academy of the Seventh Ministry of Machine Building, final assembly of the nuclear warhead was carefully checked out.

At about 9 o'clock on the 26th, the test committee determined that the launch time would be 9 o'clock on the 27th. Zhou Enlai approved this launch time and asked people to calmly do their job. Launch team No. 2, under the leadership of Yan Zhenqing [7346 2182 3237] accurately carried out several hundred operations; all preparations fully met the requirements. The nuclear missile was ready for launch.

At 2 AM on the 27th, the target zone suddenly had 6-7-grade strong winds. This weather change was not good for safety in the target zone. Zhang Yunyu, being in charge of the target zone, prepared for the worst-case scenario and organized people for emergency evacuation preparation. Meanwhile, he kept a close eye on the weather. At this key moment, the weather department of the base made real-time observations of the weather and, after rigorous calculation, determined that the strong wind would move out of the target zone at 8 o'clock at a speed of 50 km/hr; the weather would then turn fair. That forecast turned out to be very accurate and the strong winds indeed moved out of the region at about 8 o'clock.

At about 9 o'clock, the launch commander gave the launch order. Immediately, the missile was ignited and leaped into the air. Following the program, it ascended, turned, and flew in a westward direction. After separation from the missile body, the warhead flew toward the target zone as programmed. The observation instruments in the target zone aimed at the incoming warhead and the remote sensing instruments received radio signals for "target acquired!" and "remote sensing signals normal!" At 09:09:14, the nuclear warhead exploded above the target zone at an altitude of 569 meters. It turned into an incandescent fireball and emitted a blinding flash. After some violent churning of smoke and cloud, a mushroom cloud slowly rose. All the measurement instruments in the target zone functioned well and obtained data. Preliminary test results showed that the explosive power was in agreement with the theoretical design values. The test was a success.

The success of this test showed that China now had a practical nuclear missile. It was highly significant for China in terms of an accelerated pace for nuclear weapons development and a stronger national power. In the meantime, China also gained the full experience of developing a nuclear warhead. After that, other models of China's surface-to-surface nuclear warheads did not go through this type of actual flight test.

Section 5. First Hydrogen Bomb Test

On 28 December 1966, 2 years and 2 months after its first atomic bomb test, China successfully exploded its first hydrogen bomb on a tower in Lop Nur. Half a year after that, on 17 June 1967, China conducted its first successful hydrogen bomb airburst test.

(1) First Hydrogen Bomb Principle Test

At the end of December 1965 the Central Special Committee approved a principle explosion test of a hydrogen bomb to be conducted around the end of 1966. In early April 1966, the Defense Science Commission organized a study of the principle test for a hydrogen bomb. After analysis and debate, it was concluded that the spare steel tower for the first atomic bomb test could be used for the hydrogen bomb principle test. The Engineers Research Institute was to redesign the room for installing the hydrogen bomb and the hoist system. In the meantime, the measurement requirements of the hydrogen bomb principle test were studied. New measurement items were added and the measurement tasks were assigned to various units. Subsequently the nuclear test base decided the position of the steel tower and formulated the experimental plan. New measurement items were determined and needed instruments were arranged.

In mid-June, the Defense Science Commission reviewed the experimental plan, discussed the safety measures for nearby residents in the downwind direction, and investigated the effects test plan. The commission asked that preparations for the tests be completed by 1 December. The Central Special Committee approved the test plan and work assignment of the Defense Science Commission. Preparations continued at the test site by the participating units.

Engineering Preparation

This test involved a total of 113 engineering projects and needed 1,400 kilometers of electric cable. The test base used only 5 months to complete the projects with acceptable quality. The steel tower construction began on 18 June and was completed at the end of October. The total number of working days was less than 100 and it took 80 days less to construct than the first tower.

Measurement Preparation

The main issues of the measurement preparation were to determine which measurement data should be used to evaluate the success of the hydrogen bomb test, and which techniques should be used to acquire these data.

Theoretical designers and measurement experts discussed and formulated the test items. To evaluate the working condition of the hydrogen bomb in the initial phase, four new test items were added. These tasks were accomplished by the cooperation of a number of institutes, including the Nuclear Weapons Institute, the Atomic Energy Institute, the Physics Institute of the Chinese Academy of Sciences, the Shanghai Institute of Optics and Fine Mechanics, the Xi'an Institute of Optics and Fine Mechanics, the Changchun Institute of Optics and Fine Mechanics, and Zhejiang University. The effort was led by the Nuclear Weapons Test Institute. The test employed 1,014 pieces of instruments and required only 1 month to finish the on-site installation.

Safety and Protection

Compared with previous tests, this test was characterized by greater power, lower explosion point, and greater surface contamination. The power of the hydrogen test was hampered by the steel tower and other field conditions. Even with reduced load of fission and fusion materials in the design, its explosive power was still 5 to 6 times greater than China's first atomic bomb. To reduce the impact of radioactive fallout on the test zone and the downwind direction, experts from the health department of the Defense Science Commission and the Military Medical College made exhaustive studies of safety issues; their consensus was that the test would not affect the health of the residents. Studies by Cheng Kaijia and others had shown that the weather conditions at the test must be carefully chosen. In addition, the ground surface within 230 meters of the tower base must be reinforced with cement and rock to reduce the amount of loose soil swept into the cloud. Simulation tests made with conventional explosives showed that these measures were equivalent to raising the steel tower by 60 meters. The safety of the test was assured.

Testing the Explosion Effects

To further investigate the effects of the hydrogen bomb explosion on structures and weapons and to study the biological effects, the Defense Science Commission organized 16 military units and arranged 81 tests using 1,377 articles of 158 different types.

Test Command and Logistical Protection

In formulating the test plan for this test, the nuclear test base recognized the complexity and safety requirements of the test. Preparations were initiated for communications, air travel, weather, action plans, safety protection, emergency evacuation, and results recovery. The test was conducted in a cold winter and the air temperature at the test zone was about 22°C below zero. The test base prepared for personnel and equipment protection against the cold. They organized 68 food service units, stored 100,000 kilograms of vegetables and maintained a drinking water supply using 50 water trucks.

Having directed the nuclear missile test at the Northwest General Missile Test Base, Nie Rongzhen came to the nuclear test base again on 31 October and inspected the preparation for the hydrogen bomb principle test. He telegraphed Zhou Enlai and reported the remaining weak links in the test and argued strongly for conducting the test in December or the following January.

Following Zhou's order, the Second Ministry of Machine Building made an extensive review of the production of the hydrogen bomb device. The Defense Science Commission sent Hu Ruogu to the Northwest Nuclear Weapons Development Base to solve some problems in the test preparation. Because of the tight schedule, Hu consulted with the test base and Air Force leaders and decided to fly the hydrogen bomb to the test site.

On 11 December, Zhou Enlai chaired a Central Special Committee meeting and agreed in principle to the arrangements made by the Defense Science Commission and the Second Ministry. Zhou agreed to a test date in late December or early January. The meeting stressed that, because the radioactive contamination of the test must be tightly controlled, the test had to be conducted in the right weather on the surface and at high altitude. Contamination of the test zone and the downwind direction had to be prevented as much as possible. The Central Special Committee also assigned Zhang Zhenhuan as the chief commander of the test.

After the preparations were basically ready, an all-site joint practice and a comprehensive rehearsal were conducted respectively on 18 and 20 December. Problems revealed in the practice were resolved.

The hydrogen bomb device to be used in the formal test was delivered to the test zone at 5:20 on 21 December. Assembly of the bomb was completed on the 25th and Nie Rongzhen flew into the test zone on the 26th to direct the test.

In the afternoon of the 26th, the hydrogen bomb device was hoisted up the tower. In the evening, Nie Rongzhen studied the weather with Zhang Zhenhuan and other members of the test committee. Zero hour was set at 12:00 of the 28th. At 19:00 on the 27th, Zhou Enlai telegraphed his approval.

From 2100 on the 27th to the early morning of the 28th, the detonator of the hydrogen bomb was installed. After inspecting the exterior and components of the hydrogen bomb, installers withdrew from the tower.

At 12:00 on 28th, the hydrogen bomb exploded on schedule. A large amount of data were taken after the explosion, particularly data on the thermonuclear reaction process, the reaction rate of the lithium deuteride-6 and the fusion power. Based on the integrated analysis of the measured data, the explosive power was estimated to be 122,000 tons of TNT equivalent. The test was a success.

This test was a hydrogen bomb surface test whether one considers the theory, the structure, or the measured data and results. The success was proof that China had

mastered the key technology for making the hydrogen bomb. It was another milestone in China's nuclear weapons development history. After the United States, the Soviet Union, and the United Kingdom, China became the fourth nation in the world to master hydrogen bomb technology.

Because the weather and protection department of the Nuclear Test Base had chosen the appropriate wind direction to conduct the test, the central axis of the radioactive cloud missed the residential area downwind from the explosion. After the explosion, from 1500 hours 28 December to 30 December, the Air Force flew 27 sorties according to the plan. Radioactive clouds and smoke were surveyed at different altitudes. Measurement results showed that the radioactive smoke and clouds did not cause any adverse effects in the regions they passed over.

(2) First Hydrogen Bomb Airburst Test

From 30 to 31 December 1966, Nie Rongzhen held a meeting at the nuclear test base. The meeting was attended by Qian Xuesen, Peng Huanwu, Zhu Guangya, Chen Nengkuan, Cheng Kaijia, Yu Min, Zhou Guangzhao, and Fang Zhengzhi. These experts all agreed that the hydrogen bomb principle test was a success. They recommended that, based on the design principle, structure, and bomb body, the next step should be the development of a million-ton full-power hydrogen bomb for airburst. This approach should be recognized as the direction for future medium-range and long-range surface-to-surface hydrogen bomb warheads. After some more discussion, it was decided that the hydrogen bomb airburst test should be conducted before 1 October 1967.

In early February 1967, several scientists in the Nuclear Weapons Institute of the Second Ministry of Machine Building suggested to Hu Ruogu and Zhu Guangya that the theoretical design of the full-power hydrogen bomb could be finalized in February and the test date should be moved forward. They wanted to explode the hydrogen bomb by 1 July, before the French could explode their bomb. The Defense Science Commission carefully studied the situation with the Second Ministry, the Nuclear Test Base, and the Air Force and briefed Zhou Enlai and Nie Rongzhen on 20 February about the preparation progress for the first airburst test of the hydrogen bomb. The Commission suggested that the test be conducted before 1 July. Zhou and Nie consented to the new schedule. The Nuclear Test Base and the Northwest Nuclear Weapons Development Base then formulated their respective execution plans and preparations for the test began in March.

The carrier for the test was a Hong-6A aircraft. The parachute-equipped bomb was to be dropped and the explosion was to take place at an altitude of 3,000 meters. (This was referred to as the "aircraft-chute-bomb test.") According to theoretical design, the power of the hydrogen bomb should be between 1.5 million and 3 million tons of TNT equivalent. The bomb's shell was designed by the Northwest Nuclear Weapons Development Base and the bomb body parts were manufactured by the surface-to-surface missile assembly plant of the Seventh Ministry of Machine Building. The parachute was developed by the No. 513 Plant of the Third Ministry of Machine Building. Modification of the bomb racks of the two Hong-6As was made by a modification group consisting of personnel from the Air Force, the Second Ministry and the Third Ministry, with the Xi'an Aircraft Plant of the Third Ministry taking the lead. These units all accomplished their development, manufacturing and modification tasks for the bomb, parachute, and aircraft.

After modification, the Hong-6As participated in a flight test to evaluate its parachute and to verify the trajectory. The test was conducted from 15 March to 3 April at the Northwest General Missile Test Base. Test results showed that the trajectory met the design requirements and the control system on the bomb functioned normally. The parachute's structure, strength, and opening sequence were normal. After some revision and repeated tests, the design was finalized and the parachute was put into production in early April. This test also proved that the modified aircraft could satisfy requirements. The Nuclear Test Base sent people to participate in the test and to become familiar with the operation of the aircraft, parachute, and bomb. These activities formed the basis for the formal test.

This test was characterized by the high power of the bomb and by the high explosion altitude. An important component of the test was to ensure the safety of the aircraft and the inside and outside of the test site. The Defense Science Commission formed an aircraft safety computation group with personnel from the Northwest Nuclear Weapons Developments Base, the Third Ministry of Machine Building, the Nuclear Weapons Institute, and the Air Force Command. The group made careful calculations for the safety of the pilots and the aircraft based on the specified flight altitude, speed, bomb dropping conditions and explosion altitude. They concluded that the aircraft and the personnel would be safe for an explosive power of up to 4 million tons of TNT equivalent. Heeding the request of the Defense Science Commission, the Nuclear Test Base carefully investigated the safety problems within and without the test zone. Learning from previous nuclear tests, a strict safety protection plan was formulated. Under the guidance of the General Staff weather bureau, the test base formulated a complete weather protection plan. A weather forecast network was formed by the General Staff weather bureau, the Lanzhou Air Force weather station, the weather department of the test base, and other weather stations in the vicinity.

To organize the test, the Nuclear Test Base consolidated the experience of previous tests and carefully formulated test plans, communications plans, and other test preparations.

Thirty-eight measurement items were scheduled for the test; there were 493 pieces of equipment and 53 effect tests. In addition to the usual sample acquisition by flying into the mushroom cloud, this test would for the first time launch a solid fuel rocket to acquire radioactive particle samples. The solid rocket was developed by the Eighth Academy of the Seventh Ministry of Machine Building. The rocket launcher was produced by plants of the Sixth Ministry of Machine Building.

Because of the greater explosive power, the original control system on the ground was no longer sufficient. Xin Xianjie and other scientists of the control technology laboratory in the Nuclear Weapons Institute independently designed and developed a sensitive, reliable, and energy-saving second-generation control system capable of long-distance remote control. They worked around the clock to complete the assembly and testing ahead of schedule.

The engineering tasks of the test were very demanding. Although there were more than 10 permanent shops and several dozen large effect engineering projects available, it was still necessary to build 327 new test facilities. The requirement for equipment and facilities was solved by the State Planning Commission and the Ministry of Materials. To save construction time, the test base volunteered to assume engineering design. Engineers were on site to direct the construction and to assure speed and quality.

The test base established a command in the experimental zone on 25 April; 6,185 technical and security personnel from 28 military and civilian units moved into the test zone and began their work. Meanwhile, Hong-6A aircraft of the Air Force were transferred to the test base airport and began air-drop exercises.

On 9 May Zhou Enlai chaired a Central Special Committee meeting to review the preparation of the hydrogen bomb air burst test preparation. The meeting asked the workers to repeatedly check the various steps of the test to make sure that the test was successful and safe. Health protection and other safety measures had to be taken in regions over which smoke and cloud would pass. Protection preparations also had to be made in regions where accumulated radioactive dosage could exceed safety levels. Emergency response plans had to be prepared to prevent accidents. The Defense Science commission was asked to finish all the preparatory work by 20 June. The Central Special Committee also agreed to have the Party Committee chairman of the Nuclear Test Base be in charge of the on-site command of the test. Zhang Zhenhuan and Li Jue were also assigned to participate in leadership roles.

The Defense Science Commission accomplished the requests of the Central Special Committee by consulting with the relevant military and civilian departments. The test base made a comprehensive analysis of the weather data in and out of the test zone and in regions to be covered by smoke and clouds for the period 1961 to 1966. They also consulted many times with the General Staff weather bureau. On 30 May they submitted the weather forecast for June, estimating the possible dates for good weather. All units finished their instrument installation and adjustment and conducted an all-site combined test on 1 June and 3 June.

Piloted by Xu Kejiang [1776 0344 3068] and Zhang Wende [1728 2429 1795] the two aircraft were responsible for dropping the bomb; they trained very hard. By 10 June, they had flown a total of 53 sorties and dropped 35 dummy bombs. Most of the landing points were within 500 meters of the bull's eye. The air force decided that Xu's plane would be the official plane and Zhang's plane would be the back-up.

On 3 June, a Hong-6A was practicing the third drop of a weighted bomb and the main parachute ripped in the air, which caused the bomb to hit the ground in free fall. After the incidence, Zhang Yunyu, Zhang Zhenhuan, and responsible personnel from the Third Ministry, the Northwest Weapons Development Base, and the Air Force conducted an on-site investigation to analyze the cause. This incidence attracted a high degree of attention from leaders like Zhang Zhenhuan and Zhang Yunyu. They studied with the technical staff and improved the reliability by adopting local reinforcement and better folding methods.

On 5 June, the official hydrogen bomb was readied by the Northwest Weapons Development Base. Various components of the hydrogen bomb were repeatedly inspected for quality before it left the plant. On 8 June, the hydrogen bomb arrived at the base assembly shop. The crate was opened and the components of the bomb were found to be in sound condition.

On 12 June, the Central Special Committee heard a briefing by Luo Shunchu [5012 5293 0443] about the completion of the test preparations. Zhou Enlai pointed out that the strength and normal opening of the parachute were crucial to the safety of the test and should be treated carefully. He ordered Zheng Hantao [6774 3352 3447] and relevant people in the Third Ministry of Machine Building to the base and make one more inspection of the parachute. He also ordered an overall inspection of the hydrogen bomb after the comprehensive preview on 13 June. Zhou asked Nie Rongzhen to supervise the test and specific tasks were supervised by Zhang Yunyu, Zhang Zhenhuan, Li Jue, Yuan Xuekai, and Deng Yifei.

At 9 o'clock on 13 June, an all-site comprehensive preview was conducted. The Hong-6A dropped a "cold" bomb with a detonation control system but without a nuclear payload. The reliability of key components was evaluated and various operators further practiced their skill.

After the comprehensive rehearsal, the base dispatched personnel to the three settlement points within 150 kilometers of the test zone to organize protective measures for the residents. Leading cadres also went to key

positions to look for oversights and to anticipate preventive activities. Preparations were again thoroughly checked. They also formulated a test zone safety and protection plan for a surface nuclear explosion.

Heeding Zhou Enlai's request, Luo Shunchu and the General Staff studied the safety and protection problem in case of an accident. They formulated detailed plans and Zhou approved them. A safety protection group was formed with people from the General Staff, the General Logistics Department, the central health department, the chemical defense troops, the General Staff weather bureau, and the Defense Science Commission. The group was responsible for unified command of emergency activities in case of an accident. The Lanzhou Military Region assigned one leader for the unified command of safety and protection in the Gansu, Shaanxi, and Ningxia region. The Health Ministry, the General Logistics Department, and the chemical defense troops formed a joint technical group and began working under the direction of the Lanzhou Military Region. The Lanzhou Military Region established command posts at Dunhuan and other places to direct safety and protection tasks. For emergency evacuation of residents, the Railway Ministry organized four trains to stand ready between Yumen and Hami at zero hour. The General Logistics Department and the Defense Science Commission have also grouped more than 300 motor vehicles to stand ready in the Dunhuan region. The health department, and the General Logistics health department drafted 50 medical personnel and formed a medical team. The team traveled from Beijing to Dunhuan, Xi'an, and Hongliuyuan region on 16 June. Meanwhile, a backup medical team was also on call in Beijing.

On 16 June, Nie Rongzhen arrived at the nuclear test site to supervise the test. Nie discussed with Zhang Yunyu and Zhang Zhenhuan and officially made 8 o'clock of 17 June zero hour.

At 8 o'clock on 17 June, the Hong-6A piloted by Xu Keijiang flew over the target to drop the bomb. Because of nervousness, the pilot missed one move and the bomb did not drop. The plane requested a repeat. The Air Force ground commander ordered: "Fly by again, be calm and don't be nervous." The Hong-6A flew over the target again and dropped the hydrogen bomb. The parachute opened according to the program. At 8:20, the hydrogen bomb exploded 315 meters from the bull's eye at an altitude of 2,960 meters. Suddenly, the blue sky was filled by an intense flash and a giant fireball appeared in the sky, obscuring the rising sun behind it. A spectacular mushroom cloud was then formed. After the explosion, the Hong-6A flew safely back to its base. The solid rocket and sampling aircraft acquired radioactive particle samples. The effects experiment obtained a great amount of data. Based on a comprehensive analysis of a variety of experimental data, the power of the hydrogen bomb was determined to be 3.30 million tons of TNT equivalent. China's first hydrogen bomb air burst was thus successfully conducted.

Personnel inside and outside the test zone were all safe. After the explosion, the Health Ministry surveyed radioactive precipitants in eight regions within the smoke and cloud track. Sampling and monitoring of water, soil, grains, vegetables and fodder did not reveal any contamination.

China's successful hydrogen bomb test was another leap forward in China's nuclear weapons development. It was the foundation for the development of strategic thermonuclear warheads and nuclear weapon-equipped troops.

Section 6. Test of Injurious and Destructive Effects of Nuclear Weapons

The explosion of a nuclear weapon causes severe damage to personnel and structures. The five injurious and destructive effects are shock wave, light radiation, early nuclear radiation, radioactive contamination, and nuclear electromagnetic pulse. Tests of the characteristics and changes of such effects serve as basis for combat application of nuclear weapons and for protection against nuclear weapons. On 2 November 1964, Zhou Enlai pointed out after hearing a comprehensive report of China's first nuclear test that China should not strive for many nuclear tests but that each test should yield as much information as possible. Future tests should include military tactical exercises. In the subsequent atmospheric tests of nuclear weapons, there have been tests on injurious and destructive effects ("effects tests") conducted by military and civilian units. The effects tests of the second nuclear test were conducted by the military training department of the General Staff Headquarters.

To study the injurious effects of nuclear weapons on personnel, the Health Ministry and the General Logistics Department placed monkeys, rabbits, and dogs at different locations and distances [from the blast]. Different protective methods were used to test the effects. Tissue damage and pathological changes were observed for the different destructive factors under different conditions. Through tests, the destructive power at different distances and in different directions was investigated. Preventive medications and treatment for acute radiation exposure were developed. Based on these results, protective methods for personnel against nuclear weapons were designed and radiation medicine was advanced.

The railway troops built a section of 1:1.5-scale simulated two-way tunnel and a section of 1:1-scale simulated two-way tunnel at the test site to evaluate the protection against nuclear weapons for the Beijing subway that was under construction at the time. In seven nuclear tests, data were collected at the top, bottom, wall, posts, exits, entrances, front, middle and rear sections and at the gates of the simulated subway. The test results showed that the subway was well protected and interior vibration was small. The subway was protected against early radiation. Even for a surface nuclear explosion, the anti-shock and ventilation systems remained sound and the animals inside the tunnel were unharmed.

Military and civilian units, including the Engineers, tested the endurance and protection of permanent structures, entrenchments, and buildings against nuclear explosions. Weaknesses were found and improvements were made in engineering design.

Effects tests were also conducted for the fast patrol boats, ships' compartments, aircraft, guns, armored vehicles, motor vehicles, light weapons, ammunition, and mines. Through these tests, the destructive characteristics and destructive radius for the various weapons were determined. Feasible protection and measures to regain rapidly combat capability were devised for field fortifications and weapons. These tests results were invaluable for combat training and for weapons development.

The General Logistics Department also conducted effects tests for uniforms, coverings, food, oil, medicine, and health items. The Ministry of Agriculture conducted effects tests for grains, seeds, seedlings, and soil. Through experiments, contamination characteristics and effective radius for protection were determined. In addition, animal tests were also carried out for irradiated food and seeds. Valuable data were obtained.

The General Staff communications troops conducted effects tests on aerial wires, underground cables, communications facilities, and radio communications equipment. Important understandings were gained for organizing communications under nuclear explosion conditions.

The General Logistics Department and the chemical troops monitored radioactive contamination of the ground surface and the personnel and material in all the nuclear tests. They gained understanding of the spread and attenuation of the radiation and the effectiveness of the various decontamination methods. This knowledge played a guiding role for organizing nuclear protection in wartime.

To explore combat experience and troop training under nuclear conditions, the General Staff organized team tactical exercises during nuclear tests. In the nuclear test on 26 September 1976, an Army division commander of a certain military region led 3,000 soldiers in a tactical exercise 90 minutes after the explosion. In the exercise they attacked the "blue team" as it was still recovering. These were exploratory activities for gaining experience in command and troop movement under nuclear explosion conditions. Combat troops and chemical troops were trained in the nuclear tests. The General Staff Headquarters and the Defense Science Commission also organized learning sessions at the nuclear test site for senior and middle level commanders in the armed forces, leading cadres in the State Council and various departments and committees, and protection cadres in the state, provinces and municipalities. These sessions increased their cognizance and tempered their ability to organize and to lead combat and to conduct various other activities.

China conducted a total of 23 nuclear tests in the atmosphere. A total of 100,000 people [people-times] participated in the effects tests at the nuclear test site. These people came from the following units: the General Logistics Department, the Navy, Air Force, artillery, the Second Artillery, armored units, the engineers, railway troops, General Staff communications troops, General Staff chemical troops, the State Science Council, the Chinese Academy of Sciences, the Ministry of Commerce, the Ministry of Light Industry, supply cooperatives, the Ministry of Agriculture, the Ministry of Foodstuffs, the Ministry of Public Health, the Ministry of Chemical Industry, the Ministry of Textile Industry, the Ministry of Construction, the Ministry of Materials, the Ministry of Communications, the Ministry of Water Conservancy and Electric Power, the Ministry of Petroleum, the Ministry of Railways, the Ministry of Posts and Telecommunications, the Ministry of Public Security, the Bureau of Broadcasting, and the First, Second, Third, Fourth, Fifth, Sixth, and Seventh Ministries of Machine Building. Aircraft flew 98 sorties. The tests involved 5 fast patrol boats, 248 armored vehicles, 479 cannons and guns, 21 surface-to-surface missiles, 786 pieces of radar and wired and wireless communications equipment, 91 motor vehicles, 104 permanent entrenchments, 66 personnel entrenchments, 407 field entrenchments, 58 bridges, and 35,000 animals. Other materials used in the effects tests included railroad rails and rolling stock, factory buildings, civilian buildings, light weapons, ammunition, fuel, crops, foods, drugs, and clothing. A large amount of information and valuable experimental results were obtained.

Following the order of the Central Special Committee and the Central Military Commission, the Defense Science Commission worked with the General Staff Headquarters and conducted two extensive reviews of the large amount of technical data from the effects tests of the late 1960s and early 1970s. They compiled 15 volumes (20 million words) of technical data on basic nuclear explosions, radioactive contamination, and protective effects. Based on these results they published the document "Injurious and Destructive Effects of Nuclear Weapons and Their Protection" for the training of troops and for engineering construction and personnel protection. Based on test data and theoretical research results, Cheng Kaijia, Sun Ruifan, Xin Xianjie, and Qiao Dengjiang [0829 4098 3068] compiled the "Handbook of China's Nuclear Effects Tests." The General Staff Headquarters, the General Logistics Department, the armed services, and the Ministry of Public Health also compiled teaching material, protection handbooks and engineering design materials for troop training and population education against atomic bombs. These technical data and information filled a void in China and provided valuable experience in training the troops, use of nuclear weapons, protection against nuclear weapons, improving the weapons, building military and civil defense facilities, waterworks, and agricultural production. It also provided real data for improving the design of nuclear

weapons and for promoting the development of nuclear weapons and experimental technology.

Section 7. Safety and Protection in Nuclear Test

The destructive effects of the shock wave, light radiation, early nuclear radiation, and nuclear electromagnetic pulse take place mainly within 1 minute of the explosion; they are instantaneous destructive effects. Radioactive contamination, on the other hand, acts over a long time and spreads over a large area; it can cause considerable damage to personnel. Therefore, the first thing to consider in atmospheric nuclear tests is the protection against radioactive precipitation and radiation. It not only affects the acquisition of test results and safety of personnel in the test zone, but also involves the safety of the Chinese people and the people of neighboring countries. The Chinese Communist Party Central Committee and the Chinese government pay a great deal of attention on it.

China has carefully studied the safety problem ever since the survey of the nuclear test site. The Lop Nur area is in the immense Gobi Desert and has no settlements. The reason that Lop Nur was chosen as the nuclear test site was that its distance from cities prevents and minimizes radioactive precipitation hazards to personnel.

Every time the Defense Science Commission arranges an atmospheric nuclear test, it organizes specialists and technical staff to make exhaustive studies of test safety and to formulate the test plan and protective measures. The mode of testing was carefully chosen. The mode was generally air burst, and at the highest altitude possible. The dust column from the explosion on the ground and the cloud should not be connected. This would greatly reduce the amount of radioactive particles in the cloud and the degree of radioactive contamination in the test site and in the downwind areas outside the test site. When the test mode had to be surface explosion or tower explosion, the number of tests and the explosive power were carefully controlled.

(1) Safety and Protection at the Test Site and Its Vicinity

In China's first nuclear test, the test party committee formulated safety and protection regulations and took strict measures for safety. For example, when the nuclear explosion took place, all the test personnel gathered in a safe zone to observe. After the explosion, the number of people entering the contaminated zone was strictly controlled. Personnel entering the contaminated zone had gone through difficult and rigorous training before the test. Personnel and equipment leaving the contaminated zone were carefully inspected in a designated area and thoroughly de-contaminated. These practices ensured the successes of the first nuclear tests and have been strictly adhered to and improved upon in the following tests.

When high-power nuclear explosion tests were conducted in the atmosphere, the Nuclear Test Base sent personnel to nearby settlement points to organize safety protection and to conduct dosage measurement. Since all the tests were conducted with westerly winds near the earth surface of the test site, the living quarters and assembly areas west of the test site and up-wind regions nearby were basically not contaminated.

Investigations were made to ascertain whether the radioactive materials released in the nuclear tests had caused local environmental contamination and whether they posed a health hazard to local residents. From 1982 to 1987, a 6-year study was made in residential regions near the test site and in control regions. These studies were made by 40 scientists from the following units: the health and protection station of the Xinjiang radiation medicine office, the Hami region immunology station, the Altay region immunology station, and the Nuclear Weapons Institute. The region of investigation near the nuclear test site refers to the nearest villages from the Lop Nur test site in different directions. The nearest one was 120 km and the farthest one was 400 km. The rest of them were about 200 km away. The control regions were located at about 700 to 1,000 km from the test site. The environments of the investigation region and the control region were basically the same except for the degree of contamination by the nuclear tests. After comprehensive, careful, and exhaustive investigation, the following conclusions were reached: the nuclear tests did not cause noticeable local contamination of residential areas and the tests had no detrimental effects on the health of the residents. The radioactivity level of foodstuffs produced in the region near the test site was within safe limits.

(2) Safety and Protection Downwind from Test Site

While paying attention to safety in the test site and the surrounding area, China also paid great attention to the safety areas in the downwind direction outside the test area. In China's first nuclear test on a tower in October 1964, the explosion time was chosen to be in the afternoon so that it would be deep into the night when the radioactive cloud drifted over settled areas downwind from the test site. This way, direct contact with the radioactive dust particles by personnel and animals could be avoided. Aerial sampling and surface monitoring of the radioactivity after the explosion showed that there was slight radioactive fallout in areas under the radioactive cloud, but the value was still within the safety threshold and no harm was done to local residents. Even so, Zhou Enlai was still concerned. On 2 November 1964, after hearing the report of the first nuclear test, Zhou ordered an escalation of the monitoring of radioactive fallout outside the test site. He also pointed out that: "There should be more surface sampling points for radioactive fallout between 20 degrees north latitude and 60 degrees north latitude. Monitoring stations should be placed at Lhasa, Chengdu, Wuhan, Guangzhou, and Shanghai in the south, Urumqi, Yumen, Hami, Lanzhou, Baotou, Hohhot, Chengde, Jinning, Zhangjiakou, Baichengzi, Harbin, Manzhouli, Hailar, and Mishan in the north, Liaodong Peninsula, Shandong Peninsula, and along the Yalu River in the middle. In the air, samples

should be taken along three lines in the East, the Southeast, and Northeast. Other samples should be taken for fresh water, sea water, vegetables, plants, and fruits." The Defense Science Commission thoroughly implemented Zhou's instructions.

To ascertain the direction of cloud movement, development trend, and radioactivity dosage, the Defense Science Commission detected, sampled, and measured the radioactive cloud outside the test zone with aircraft equipped with self-recording micro-Roentgen meters and with radiation-monitoring weather balloons. This monitoring was done with the participation of the General Staff weather bureau, the General Staff chemical troops, the Air Force, and the Atomic Energy Institute. In each of the nuclear tests, they followed the forecast of radioactive cloud movements and acquired samples along three lines in the East, Southeast, and Northeast. Samples were taken at three altitudes. In the 23 atmospheric nuclear tests China conducted, the Air Force flew a total of 485 sorties using 283 aircraft of six different models. Beginning in 1967, weather stations in regions passed by the radioactive cloud deployed radiation weather balloons according to the direction and speed of the clouds.

To reduce the radioactive fallout in regions downwind from the test site, the Defense Science Commission also agreed to have the General Staff weather bureau enhance the forecast of cloud movement and made precipitation in regions passed by the cloud one of the considerations in deciding a test date. For example, the large atmospheric nuclear explosion that took place on 29 September 1969 was originally scheduled for 26 September. However, in the morning of the 26th, the weather changed. Forecasts had the radioactive cloud moving along the border and into a neighboring country as it moved in the downwind direction. At 6 AM, Zhou Enlai heard the report of leaders of the Defense Science Commission and decided to conduct the test on a different date in order to assure the safety of residents in a neighboring country. The decision was first reported to Mao Zedong and his approval was obtained.

To assess the dust fallout situation in China after the nuclear tests, the Ministry of Health established the Industrial Hygiene Institute as a national center and built 46 environmental radiation monitoring stations around the country. In each nuclear test, these stations measured the amount of dust fallout, radioactivity concentration in near-surface air, radioactivity in rain water and water sources, the degree of contamination of vegetables and gamma ray dosage at the ground surface.

To study the long-term effects of radioactive contamination, the Ministry of Health made two large-scale surveys, in 1975 and 1977, respectively, on the radiation exposure and health situation of residents in Dunhuan and Jiuquan. The surveys were conducted by the Industrial Hygiene Institute of the Ministry of Health, the Industrial Hygiene Institute of Gansu, and chemical troops in the Lanzhou Military Region. In June 1979, these units made a comprehensive analysis of the monitor data and residents health data collected in the various nuclear tests. The conclusion was that radiation exposure of the residents was minor; it was less than the natural radiation background of the region and also less than the limit set in the "Radiation Protection Regulation." In comparison studies, there was also no evidence that the residents' health had been affected by the dust fallout of the nuclear tests.

China has acquired a great amount of data on aerial radioactive clouds and radioactive dust fallout outside the test zone in its many atmospheric nuclear tests. It has learned the movement behavior of radioactive clouds and the characteristics of radioactive fallout. It has also found empirical calculation methods for forecasting the path and concentration of radioactive clouds and the contamination of ground, air, and rain water by fallout. These findings were crucial for the protection of troop movements and residents' safety. Based on the measured data and analysis of radiation dosage in downwind areas, it was concluded that China's nuclear tests posed no danger to the population of neighboring countries in the downwind direction.

Because China paid so much attention to the health and safety of the population within and without China and worked so hard on safety and protection, all its 23 nuclear tests were conducted safely.

Section 8. Underground Nuclear Tests

In underground nuclear tests the nuclear device is buried at a certain depth underground and then detonated. Generally there are two types of underground tests: tunnel nuclear tests and shaft nuclear tests. Compared to atmospheric nuclear tests, underground tests require a higher degree of technology, more construction work, and a higher cost; however, they have certain unique advantages. Such tests not only contain the radioactive products underground, which is desirable in terms of environmental protection and secrecy, but also facilitate the collection of radioactive product samples. In particular, physical diagnostic measurements may be carried out very close to the nuclear device. Results of underground tests are useful for improving nuclear weapon design and for studying the linear destructive effects of radiation. These data are indispensable in the theoretical research and design of nuclear weapons. The move from atmospheric tests to underground tests was necessitated by the objective needs of nuclear weapons development.

(1) Tunnel Test

In a tunnel test a specially designed long tunnel is dug into a mountain. The nuclear device and various probes are installed in the tunnel. After the tunnel is filled and sealed in a special way, the nuclear device is detonated.

Following instructions from Zhou Enlai, the Second Ministry of Machine Building and the Defense Science Commission made a preliminary investigation of the underground nuclear testing problem. Later, the Defense

Science Commission followed the decision of the Central Special Committee and organized the Nuclear Test Base to formulate a plan for nuclear tests in tunnels and in shafts. To this end, Zhang Yunyu, Zhang Zhishang, and Zhang Ying did a careful site selection for underground nuclear testing and proposed that the site for the tunnel test be chosen at Nanshan in the Nuclear Test Base. The proposal was approved by Zhou Enlai. In early 1965, an extensive study was organized by the Defense Science Commission and the site of the Nanshan underground test was finalized. The study was conducted by the Defense Engineering Design Institute of the Engineers, the Geology Institute of the Chinese Academy of Sciences, the Ministry of Petroleum, and the Ministry of Geology. The study investigated the geology, the hydrogeology, the rock chemistry, and the mechanical properties of rocks. Later, the Nuclear Weapons Institute conducted theoretical calculations for the propagation of shock waves in rocks and for the self-sealing mechanism of the tunnel. Simulation tests were performed for chemical explosives and the theoretical parameters were unified and revised. These activities were the technical preparation for the underground nuclear tests.

China originally planned to conduct its first underground test using a tunnel in May 1966. Later, the plan was temporarily halted by the Central Special Committee because China wanted to come up with a flight-tested warhead as soon as possible, and to concentrate resources on the technological breakthrough of the hydrogen bomb. After the first successful air burst test of China's hydrogen bomb in 1967, the Defense Science Commission held detailed discussions with experts, including Wang Ganchang and Cheng Kaijia, in October and November regarding the objectives, test items, and engineering requirements for China's first underground test. It was decided that the principal objective of China's first tunnel nuclear test was to explore the characteristics of China's underground nuclear tests and to conduct near-field physical measurements of the nuclear bomb in order to provide data for improving nuclear bomb design. In May 1965 the construction and progress of the various tasks were coordinated at the Nuclear Test Base.

After redefining the tasks, the construction for the underground test continued in the spring of 1969. Because of technical requirements, there were a number of modifications. The tunnel construction involved extensive engineering, complex technology, limited working surface, and high risks. In view of these characteristics, the Nuclear Test Base organized an engineering command, a technical guidance command, and a tool and materials supply command and established a sound construction procedure. Workers were fearless and worked around the clock in the hot and stuffy tunnel. Together, they improved the technology and completed 54 experimental engineering projects in June, according to plan and meeting quality standards. Testing and scientific experimentation were arranged by the Nuclear Weapons Design Academy and the Nuclear Weapons Institute. After 2 months, they completed the installation and testing of 400 pieces of equipment in early September.

To assure safety, the Defense Science Commission met at the test site in April 1969 and worked on technical measures that would prevent mishaps in the test such as "blowing the top," "jumping the gun," "misfire," and "dud."

In the evening of 10 August, the Central Special Committee heard the report of Deputy Commander Zhang Ying of the Nuclear Test Base regarding the preparation of the test site. Zhou Enlai stressed that the test must be done safely so that accidents such as "blowing the top" and leaks of radioactive materials could be avoided. The Nuclear Test Base again calculated the resistance and wave absorption in the tunnel and analyzed the various external environment factors, and they were sure that the preventive measures taken would prevent "jumping the gun." On 15 September, the nuclear device was placed in the explosion chamber and the tunnel was subsequently sealed. At 0015 on 23 September, China successfully detonated its first tunnel nuclear test. The tunnel's self-sealing mechanism worked and there were no "blowing the top" or "jumping the gun" incidents. The yield of the nuclear explosion was basically in agreement with the design.

To understand the characteristics of tunnel nuclear tests, and to verify the agreement between the theoretical design and the actual explosion, the tunnel and explosion chamber were excavated from 1970 to 1971. The height and the size of the "chimney" caused by the explosion were measured and the effectiveness of the self-sealing and filling function were investigated. Three cores were drilled to collect the radioactive material generated by the explosion. First-hand data of these investigations showed that the self-sealing technology and the specimen core technology were successful. The theoretical understanding of the fluid mechanics of an underground nuclear explosion was basically in agreement with reality. Diagnostic measurements made near the nuclear bomb yielded important data and pointed to new directions in the development of near-field physical measurements. Through this test, understanding of underground nuclear test was validated and enhanced and major interference problems were revealed in the near-field physical measurements. Because the test was conducted in limestone, it generated a great amount of carbon monoxide and carbon dioxide, which were detrimental to the safety of radiation chemistry analysis. It was not desirable to conduct underground nuclear tests in limestone. The Nuclear Test Base therefore moved the test site to the granite Beishan [North Mountain] underground test site.

To gain more experience in underground nuclear testing, to improve the weapon design and to test new nuclear principles, five more tests were conducted from 1975 to the end of 1988 at the Nanshan and Beishan test sites. In the second tunnel nuclear test on 27 December 1975, important data were obtained in the near-field physical

diagnostic measurements. These data helped solve the technical problems in tunnel self-sealing, rapid sample acquisition, and electromagnetic interference in near-field physical measurements. In the third tunnel nuclear test on 17 October 1976, new advances were made in rapid sample acquisition, and new understandings were gained in nuclear explosions in granite and anti-interference technology. In the fourth nuclear tunnel test on 4 May 1983, rapid sample coring was achieved for the first time. Abundant high-quality solid samples of radioactive materials for chemical analysis were obtained in the first drill. Meanwhile, major advances were made in near-field physical measurement technology. On 19 December 1984, the fifth nuclear tunnel test was conducted. The test was made for a new principle in nuclear weapons and the experiment was a success. China had made a major breakthrough in new nuclear weapons technology.

(2) Shaft Nuclear Test

In a shaft test the nuclear device and various sensors are lowered to the bottom of a large-diameter well, the well is then filled and the nuclear device detonated. Due to the depth limitation of a tunnel test, most mountains cannot satisfy the experimental requirements. This is particularly true for high-power explosions. In a shaft test, there is usually no limit to explosive power. As long as the underground rocks are suitable for testing, a shaft can be drilled to the depth needed for the particular explosive power. For this reason, the shaft test mode has become the principal method for underground nuclear testing.

In April 1967 China chose the Xinge'er region northwest of Lop Nur for the shaft test site. After years of effort, a complete experimental facility and living quarters were established and various equipment developed. The necessary conditions for conducting the test were basically provided.

A shaft nuclear test requires a well with a large diameter and a certain depth. Drilling such a shaft required a large drilling rig. In October 1966, the Nuclear Test Base, the Nuclear Weapons Institute and engineering departments surveyed coal mines, oil fields and machinery departments and submitted a proposal to the Defense Science Commission to develop a large-diameter hard-rock drilling machine. On 9 May, the Central Special Committee approved the proposal and decided that the drilling task should be the responsibility of the Ministry of Coal Industry (later the Defense Science Commission took charge) and the machining task should be given to the First Ministry of Machine Building. Other participating units included the Nuclear Test Base, the Coal Institute, the Lanzhou Petrochemical Plant, the Luoyang Institute of Mining Machinery, the Shanghai Institute of Coal Mining Machinery, and the Beijing Institute of Mining. In October 1967, work began on design planning. In 1971, the drilling machine was assembled at the Lanzhou Petrochemical Plant and moved to the Nuclear Test Base. The development of the large drilling machine was the key to shaft tests of nuclear weapons. In 1973, the drilling began at the test base. By April 1975, the first granite shaft 300 meters deep and 2.5 meters in diameter was drilled. Later, several other shafts were drilled and drilling techniques gradually improved.

In April 1975, the Nuclear Test Base submitted the proposal for the underground shaft nuclear test to the Defense Science Commission. Extensive discussion and deliberation were then made by the Nuclear Test Base, the Nuclear Weapons Design Institute, and the Engineering Design Institute of the Defense Science Commission. In March and April 1977, the Defense Science Commission reviewed the general plan for conducting the first underground shaft nuclear test and coordinated the technical tasks of engineering, testing, and nuclear device. A 200-meter-deep granite shaft was chosen for the test. The main goal of the test was to learn the skills for shaft testing and to gain experience in adopting engineering techniques, test safety, and nuclear device testing techniques to the underground shaft environment. The engineering design and the design of non-standard equipment were assumed by the Engineering Design Institute of the Defense Science Commission. The Nuclear Weapons Institute was responsible for the design and development of the enclosure for the nuclear device and the sealing of the explosion chamber.

The construction of the shaft began in April 1977. Since the flooding rate of the shaft was 9.3 tons per hour, the sealing of the nuclear device and test safety were jeopardized. To counter this problem, the flooding was reduced by sealing and reinforcing the shaft wall. The Daqing oil field on more than one occasion sent people to the test site to advise the pumping of water. The technology team of the test base sealed the water by spraying grout and by grout injection. After 15 months of tireless work, the shaft construction was completed. The flooding rate was reduced to 2.5 tons per hour, basically satisfying the test requirement.

In July 1978, hoisting and installation began. To be fail-safe, a test hoisting was done first. After gaining some experience in hoisting, the official hoisting was done in late September. When the official hoisting was performed, the nuclear device was placed in a special sealed container. Measurement probes and the sealed nuclear device were then placed in a special sealed explosion chamber. Tubes were used to connect the container, the probes, and the cables into an integrated whole, which was slowly lowered to the bottom of the shaft. The hoisting of the assembly was tricky and its procedure needed rigorous control. The installation personnel of the test base adhered to a position responsibility system and safely lowered the device to the bottom of the shaft. The shaft tube back-filling began on 2 October. Back-filling was performed while the water was being pumped. After 12 days of hard work, 1,400 cubic meters of space was back-filled and the quality was completely in keeping with requirements. The difficult task of constructing and filling the shaft was done by the 1st Company, 6th Battalion of the technology team of

the Nuclear Test Base. This courageous company was awarded the title of "New Long March Commandos" by the Central Committee of the Chinese Communist Youth League.

To ensure a safe and successful test, the work to eliminate errors and duds was firmly grasped. The Nuclear Weapons Design Institute repeatedly inspected the detonation system and the operating procedures. Static electricity tests were performed for the detonation cable and lightning strike prevention was implemented. After the nuclear device was lowered to the bottom of the shaft, the water level and the temperature and humidity in the sealed container were monitored day and night. Extensive safety measures were made for the test cable and the detonation cable. Emergency reaction plans were also formulated.

At 9 o'clock on 14 October 1978, China successfully conducted its first shaft nuclear explosion. The test achieved total closure. Three hours after the explosion, radioactive gas samples were obtained. On the 16th day radioactive solid samples were acquired. Satisfactory results were obtained in safety, engineering, measurement, and sampling.

Starting in 1981, China moved its atmospheric nuclear tests underground. To advance new principles of nuclear weapons and to improve test technology, four more shaft tests were conducted by 1988. In the second and third test, the water level was low, the container size was small and grout sealing and submerged pumping were done manually. More items were tested than the first test. The third test used an inclined shaft with a maximum tilt of 6.1 percent (the two previous tests used 2 percent or so). The lowering of the explosion chamber was done with the aid of steel pipes. Experience was gained in tilted shaft construction and in lowering. The shaft for the fourth test was constructed using steel-sleeved pipes and the dry shaft method. A measurement frame was used for the first time. Through this test, the design and construction of a dry shaft using the telescopic tube method were mastered. Experience was gained on near-field measurement and electromagnetic interference prevention, and new breakthroughs were made in measurement technology.

Because of the high groundwater level, flooding was more severe. Using a shallow-water test mode, the construction was difficult, the construction time was long, the cost was high and it was unsafe for the workers to work in the shaft. To find a better and more economic method, on 5 June 1987, China tested a nuclear device of greater explosive power using a medium shaft depth and an all-water-level mode. Meanwhile, experience was gained in measurement, anti-interference, cable sealing for high pressure, and shaft back fill. This signified China's new development in shaft test technology.

The main issue in ensuring safety in underground nuclear tests is to prevent radioactive material from emerging from the ground. In China's five shaft tests the back-filling and sealing of the shafts ensured safety. Experience had been gained in theoretical calculations, engineering designs, and construction techniques.

China's shaft nuclear tests covered the range of water levels and well depths. Pronounced improvements have been made in the development of large-scale equipment, and in engineering design, drilling, shaft construction, hoisting, back-filling, and sample drilling. In terms of measurement techniques, China went from a small container to a large container, test scaffolds, multiple tubes and near-field physical measurements. In near-field physical measurements and radiochemistry measurements, theoretical and practice were investigated to a greater depth and weapons physics was studied for weapons design. This showed that China's underground nuclear test capabilities have improved greatly. China is further developing its underground nuclear tests, investigating new measurement techniques, and improving current equipment.

From 1964 to 1989, China conducted a total of 34 nuclear tests, of which 23 tests were in the atmosphere and 11 were underground. Compared to the 800 nuclear tests in the United States and the 600 tests by the former Soviet Union, China's number of nuclear tests was quite small. Since a nuclear test is a scientific activity, it naturally has a dual possibility. Even though three of China's tests did not succeed, the success rate and efficiency are still quite high. By following Zhou Enlai's policy of "serious, detailed, stable, and reliable," China has achieved a great deal. In research and nuclear weapons development, the results provided important information on the use and protection of the nuclear weapons. China has not only built a modern nuclear test base complete with various measurement modes, but also a team of experienced nuclear test personnel.

China is conducting necessary but limited nuclear tests in its nuclear weapons development program for defense purposes. China's nuclear tests will continue to improve its nuclear weapons. Such tests will not only help to achieve the established development goals, but also protect the national security and contribute to maintaining world peace.

Chapter X. Nuclear-Powered Missile Submarine

Powered by a nuclear reactor nuclear powered missile submarines can stay submerged for extended periods of time and have battle capabilities far superior to those of conventional submarines. They can also operate in a much greater range. Equipped with guided missiles, they can conduct anti-submarine, anti-ship and, land target attacks; they also possess the "second strike" advantage that land-based strategic weapons do not have. China decided to develop nuclear submarines in 1958. By 1988, China had developed the nuclear torpedo submarine and nuclear-powered missile submarine. Nuclear submarines are a major breakthrough in China's ship building technology.

Section 1. Nuclear Submarine

(1) Development in Two Steps

In 1958, shortly after the Central Committee approved the development of the nuclear submarine, the Navy Building and Maintenance Department formed a nuclear submarine group to study the general design of a nuclear submarine. In 1959, the Navy proposed the concept of an overall plan for nuclear submarines. Due to temporary economic hardship and lack of research resources, the Central Special Committee approved a plan in March 1963 to concentrate resources on key issues in nuclear power and submarine hulls.

In the mid-1960s, the national economy improved and China succeeded in copying and independently developing the conventional submarine. A preliminary design of the nuclear device was completed and progress was made on major components and materials of the nuclear reactor. On 20 March 1965, the Central Special Committee approved the resumption of the nuclear submarine project. At this time, Director Yu Xiaohong [0060 4562 5725] of the Seventh Academy in the Sixth Ministry of Machine Building and expert Huang Xuhua recommended that the nuclear submarine development project be done in two stages. The first stage was to be the development of a nuclear torpedo submarine and the second stage was to be the development of a guided missile submarine. The reason was that the technology for the submarine-to-land guided missile and other weapon systems was extremely complex. In addition, there was also the need for many technical problems for the nuclear submarine itself and for key components for the guided missile. These problems were very difficult and required a longer time to solve. By first developing a nuclear torpedo submarine, China could not only solve the technical difficulties step and step, but also make use of some of the same materials and equipment to speed up the process. The Sixth Ministry supported the recommendation and made a report to the Central Special Committee in July 1965. The plan was approved.

(2) Nuclear-Powered Torpedo Submarine

While approving the above recommendation, the Central Special Committee also demanded breakthroughs in nuclear power and its associated installation technology. It set a date of 1972 for underwater testing of the nuclear submarine. To this end, Laboratory 719 was established in the Seventh Academy to work on the design of the nuclear submarine. The new laboratory was headed by Xia Tong [1115 2717] and was based on the capabilities of laboratories 701 and 715. The leader of the new laboratory, together with its technical staff Huang Xuhua and You Ziping [1429 1311 1627], organized a study while the group was being staffed and proposed a preliminary plan for the overall design and major equipment of the submarine. The second task was technology assignment and coordination. The State Planning Commission, the State Economic Commission, the Defense Science Commission, and the Office of DefenseIndustries jointly summoned the participating departments for a briefing of the preliminary design, equipment system, and major key technologies. They studied the coordination of engineering tasks in the submarine project. Subsequently, the Office of Defense Industries organized a technology transfer from a number of departments to laboratories 719 and 715. These departments included the First, Third, Fourth, Fifth, and Seventh Ministries of Machine Building, the Ministry of Metallurgy, the Ministry of Chemical Engineering, the Chinese Academy of Sciences, the Ministry of Higher Education, the Ministry of Petroleum, the Ministry of Building Materials, the Ministry of Textile, the Ministry of Railways, the National Oceanographic Bureau, and the Ministry of Health. Later, full-fledged efforts proceeded in submarine hull design, major subcomponent and special equipment development, and material development. The third task was to build the manufacturing plant for the submarine. The Sixth Ministry Machine Building drafted nearly 3,000 workers from shipyards in Dalian, Shanghai, and Wuchang to participate in the construction of the manufacturing plant and the production of the vessel. Mao Zedong signed two telegrams authorizing the assignment of military personnel to the construction effort. With the joint military and civilian effort, the plant was built in less than 2 years. China's first anti-submarine nuclear submarine was equipped with an acoustic guided torpedo and employed a teardrop profile and single shaft propulsion. The submarine had self-sustaining power for tens of days and diving depth and underwater speed were comparable to that of foreign submarines of the same class. The vessel has seven compartments and the control room was in the second, where the periscope and various antenna gear were located. From a distance, the exterior of the submarine resembled a great gray whale.

The nuclear submarine technology is extremely complex. First, there must be a compact and reliable powerplant and a body profile good for high-speed underwater navigation. Then there must be air conditioning, air regeneration, and purification systems, underwater navigation and positioning systems, long-distance secure communications systems, underwater long-distance warning, search, surveillance, communications and target-positioning sonar systems. Finally, there must also be an anti-submarine torpedo weapons system compatible with the combat mission of the ship.

The equipment systems chosen had a direct impact on the fighting ability of the submarine, the development time and cost, and the success or failure of the project. They were the first major issues to be addressed in the discussion of the overall proposal. Different understandings and opinions were aired in the discussion. Some were concerned that, with both conventional and nuclear power, the development of too much new equipment for the first nuclear powered submarine could prevent the project from achieving a timely completion. Others believed that advanced equipment under development

and to be developed should be employed in China's first nuclear submarine in order to catch up and overtake the world standard. To unify the various views, the overall plan was analyzed specifically by the participating departments. Different views were unified on the basis of two principles approved by the Central Special Committee. These principles were: first, to develop the nuclear submarine based on practical and domestically available technology, and, second, China's first nuclear submarine should have the character of an experimental vessel but at the same time possess the major tactical and technical capabilities of a warship. It was decided that, in addition to the nuclear powerplant, the submarine should have the following new systems in order to ensure combat capability. These were the anti-submarine torpedo and the associated command control, launch, and inertial guidance systems, high-power transient transmitter, comprehensive sonar system, and an integrated air conditioning system. Other systems should employ mass-produced, domestic conventionalsubmarine equipment wherever possible. To meet the needs of submarine development, the Seventh Academy, a primary organization for the project, started a series of new specialties and organized a number of research laboratories. After several years of concentrated hard work, there were breakthroughs in seven key technologies and the anticipated goals were basically realized.

Decision on Body Profile

China's first nuclear submarine adopted the teardrop profile for high-speed underwater cruising. It was a new technology at a time when China did not have complete facilities for fluid dynamics tests. Workers of Laboratory 719 broadly surveyed domestic and foreign data and conducted theoretical analysis and investigation to select the optimal plan and parameters. They also conducted extensive experimental testing with Laboratory 702 and other units to study the basic rules for controlling a teardrop shaped vessel. Experimental verification was conducted for the chosen design in wind tunnels, rotating arm water tanks, and wave- resistance water tanks. Laboratory 719 also built a special experimental turntable for studying the submarine control and for simulating the control functions. Actual navigation tests showed that the teardrop profile had superior maneuverability and achieved an underwater speed greater than that of the conventional profile. China had achieved a big success in developing the fluid dynamic properties of the nuclear submarine.

Design of a Large-Diameter, Pressure-Resistant Hull

The, teardrop profile was stubby and had a low aspect ratio. It also increased the water displacement. The diameter of the pressure resistent hull was about twice that of a conventional submarine. Part of the structure was based on a conical shell design. Conventional design codes and computational methods proved inadequate. The safety and reliability of the pressure-resistant submarine had a life-and-death importance. Scientists engaged in structural research applied short shell plastic stability theory and explored new methods of computation. They also investigated different parts of the structure with scale models and conducted simulated strength tests for the welding of the pressure-resistant method. These tests showed that the hull design met deep dive requirements.

Development of Integrated Air-Conditioning System

The air-conditioning system is crucial to the well being of the crew and normal operation of the various mechanical, electrical, and electronic equipment. In collaboration with other plants and laboratories, Laboratory 718 of the Seventh Academy developed an oxygen generation device, a $C0_2$ removal device, a hazardous gas burning device various purification filters, and cabin air-conditioning analysis monitors. Working with Chongqing General Machinery Plant, they have also developed large capacity refrigerators for submarine use. These systems underwent on-land simulation tests, enclosed performance reliability tests, and crew endurance tests in a simulated submarine environment created by the Navy Medical Research Institute. Satisfactory results were obtained in all tests. With the sophisticated air-conditioning system and the reliable radiation shield and protection, cabin environment was safe and more comfortable than that of a conventional submarine.

Development of Nuclear Powerplant

The nuclear powerplant is a key component in the development of a nuclear submarine. The Nuclear Power Engineering Research Institute worked with other units and built a land-based reactor to simulate the submarine nuclear powerplant. The land-based simulation power device consisted of the reactor compartment, the main engine room, the auxiliary engine room, and the shaft system. The operation and function of the system were the same as that aboard a submarine. The land-based model reactor followed the principle of full simulation and provided valuable and reliable test data for the installation, testing, and operation of a submarine nuclear powerplant. In the development of the nuclear submarine, workers rigorously implemented the procedure set by the Central Special Committee, which was: "First bring the land reactor to criticality and then install the submarine reactor. First bring the land reactor to full power and then launch the submarine." By following this procedure, the nuclear reactor was successfully installed on the submarine in the first trial.

Development of underwater sound, navigation, communications and torpedo weapon system

The development of advanced underwater sound, inertial guidance, communications, and torpedo systems was conducted by four laboratories (706, 722, 707, and 705) of the Seventh Academy and by units in the Fourth Ministry of Machine Building. The long-range noise detection station used a large array and a number of new

techniques. An ultra-long-wave receiver and a high-power, ultra-fast short-wave transmitter ensured submarine activities at sea. A number of technical difficulties were overcome in the development of the electric dual plane, the acoustic anti-submarine torpedo, the deep-ocean torpedo launching device, and the digital torpedo firing command. After persistent research, the development of the inertial guidance system also reached the goal set in the plan.

The development of a nuclear submarine was a complicated systems engineering project. There were more than 2,600 meters and instruments on the submarine, 46,000 parts, 90 kilometers of cables and 30 kilometers of pipes. Equipment density was very high. The hull design for the nuclear submarine had to allow a sensible layout of the complicated system in order to satisfy the combat requirements. The design also had to ensure sound working and living conditions for the crew. To solve this difficult problem, Laboratory 719 worked closely with the nuclear submarine manufacturing plant and built a full-size plastic model by spending more than a year of time. The designers, installation crew, and navy personnel conducted simulated installation and operation. They discovered and solved numerous problems in installation and maintenance. After repeated adjustment and modification, they finalized the layout of the equipment and meters, the path of pipes and cables, and the location of more than 1,000 openings in the pressure-resistant hull. These activities ensured that the general design was successful in the first attempt.

Construction began in 1968. In order to stay on schedule as approved by the Central Special Committee, Laboratory 719 organized two design meetings and completed more than 700 design drawings in a short period of time. Half of the scientists and technical staff pitched in to help with the construction. The submarine plant divided the work into two tasks: submarine hull construction and equipment installation. Under difficult working and living conditions, the technical staff, workers, and cadres all joined in to improve the technology and equipment and made the scheduled launching possible.

Tests on the nuclear submarine began in April 1971. Electric power was generated on the nuclear reactor in July and preliminary evaluation was made for the main machinery and the power train. On 15 August, China's first nuclear submarine sailed toward the test zone for the first time. By April 1972, the submarine had undergone more than 20 test runs and logged several thousand nautical miles. Most of the tests were completed. From January to April 1974, the submarine made inspection test runs. It was delivered to the Chinese Navy on 1 August.

(3) Nuclear-Powered Missile Submarine

Research and development of China's nuclear-powered missile submarine began shortly after some results were obtained in the development of the anti-submarine nuclear torpedo submarine. In June 1967 the Navy proposed that the development of the nuclear-powered missile submarine should be a two-phase process. The first phase was to develop a nuclear-powered missile submarine on the basis of the nuclear torpedo submarine but the performance requirements should not be set too high. The second phase should be building a better submarine based on the first one. The proposal was evaluated and discussed. A decision was made that the emphasis for the first guided missile submarine be placed on the submarine-to-land guided missile weapon system and the technology for underwater launching of the guided missiles. Most of the systems on the torpedo submarine were retained, with the exception of the guided missile weapon system and some items that had to be redesigned because of the increased water displacement, crew size, and safety requirements. The main difference between the two types of submarines was the guided missile module. The missile module contained a number of launch tubes and their associated power systems, underwater hatch openings and pressure equalization system, air conditioning and temperature control system, water injection system, and equipment for missile inspection, aiming, and launch control. Equipment requiring development and improvement represented about 15 percent of the total.

The key technologies for the guided missile submarine were the underwater launching of the submarine-to-land guided missiles and the precise navigation and positioning of the submarine. Underwater launching of the missile required that the missile be launched from a depth of several tens of meters and that the missile have adequate "muzzle velocity." The missile had to maintain a normal stable attitude as it emerged from the water and this had to be achieved in the presence of waves, currents, and fluctuation of the submarine. The degree of difficulty was therefore much greater than a surface launch. For this reason, the development plan required testing on a land-based launch pad and launch tube before the underwater launch test on a submarine. Laboratory 713 of the Seventh Academy assumed the duty of research and design for the launch device. Led by Wei Naiwen [7614 0035 2429], tests were performed and a combustion-powered cold launch plan was adopted. In October 1972, an underwater launch test was conducted using a full-scale-model missile on a modified conventional guided missile submarine. The intended goal was achieved and the key technology of underwater launch was attained.

The nuclear-powered missile submarine required a highly accurate navigation and positioning system. It not only had to ensure safe underwater navigation of the submarine, but also determine the position accurately so that the missile could accurately hit the target. Laboratory 707 worked extensively on this technology. Their hard work finally resulted in the inertial guidance system and the star and satellite guidance system for China's first nuclear-powered missile submarine.

In September 1970, construction began on the nuclear-powered missile submarine. In September 1979, the

Defense Science Commission and the Office for Defense Industries named Peng Shilu as the chief designer for the nuclear submarine and Huang Weilu, Zhao Renkai, and Huang Xuhua as deputy chief designers. Overall supervision and coordination of thenuclear submarine project were strengthened. With a lot of hard work by the participating departments, China's nuclear-powered missile submarine was launched on New Year's eve 1981. In August 1983, it was put into service in the Navy.

Section 2. Nuclear Submarine Powerplant

The nuclear powerplant of the submarine consisted mainly of the reactor, the primary circuit, the secondary circuit, and the shaft system. Compared with land-based nuclear reactors, the one on the submarine was more compact, lighter, more impact-resistant and vibration resistant, tilt tolerant, versatile, and reliable. The nuclear powerplant was the key to the nuclear submarine and its development was a complex and difficult system engineering task.

(1) Research on and Design of Nuclear Submarine Powerplant

Independent research of the submarine nuclear powerplant began in 1958. At that time an experimental heavy water reactor was built with Soviet help and put into operation the Atomic Energy Institute. The first group of nuclear reactor technicians was trained and ready for preliminary study of the submarine nuclear powerplant. However, there were numerous difficulties in the independent development of a submarine nuclear powerplant and extensive research and testing were needed.

The early phase research and design of the nuclear powerplant was assumed by the Atomic Energy Institute, the Navy, and the First Ministry of Machine Building. The Atomic Energy Institute was responsible for the research and design of the reactor and its primary circuit. The Nuclear Submarine Laboratory was responsible for the research and design of the body, the secondary circuit system and the shaft system of the vessel.

In October 1958, there were some 200 technical staff in the Reactor Laboratory of the Atomic Energy Institute. Deputy Director Li Yi [2621 3015] of the Institute and Meng Gefei [1322 2047 7236] and Lian Peisheng [6647 1014 3932] of the Reactor Laboratory led the study of reactor physics, reactor design, fuel elements, thermo- and hydrodynamics, and automatic control. In March 1960 the Defense Science Commission put forth a policy that stressed that the reactor development should be followed immediately by the development of the vessel, the machinery, and the electrical missile systems. This directive moved the research and design forward at a faster pace. In June of the same year, Zhao Renkai, Han Duo [7281 6995] and Li Lefu [2621 2867 4395], under the supervision of Peng Huanwu [1756 2719 2976], repeatedly investigated, calculated, and deliberated the problems before proposing the "Nuclear Submarine Power Device Design (Draft)." This proposal contained the initial design concepts of the nuclear reactor type and the principal technical parameters. However, some controversy arose about the thermodynamic parameter in the August 1960 evaluation conducted by the Defense Science Commission and in the March 1961 meeting called by the Second Ministry of Machine Building. Departments responsible for equipment development felt that the parameter was set too high and could not be produced in China. Other departments were for maintaining the advanced nature of the submarine design and were opposed to lowering parameter values. After a 2-month investigation conducted by the nuclear submarine leadership group, it was decided that the design of the power device must be practical and the thermodynamic parameter should be set according to the actual technical level of the industry in China. In the meantime the nuclear submarine laboratory began collecting materials and started the design task. At the end of 1961, they proposed the initial design of the secondary circuit system and the shaft system. Later, based on the Central Special Committee decision to temporarily put the nuclear submarine project on hold, the Atomic Energy Institute and thenuclear submarine laboratory kept a few dozen technical staffers to continue the reactor physics, thermodynamics, and hydraulics under the supervision of Peng Shilu and Li Lefu. Also, after several years of hard work, two swimming pool type experimental reactors were completed at the Atomic Energy Institute and at Qinghua University. Research on the nuclear fuel elements, material and shielding began shortly after that.

In August 1963, the Central Special Committee approved a merger between the submarine nuclear power research and design office in the Atomic Energy Institute and the nuclear submarine technology research laboratory in the Seventh Academy. The combined unit became the new Submarine Atomic Power Research Institute (or "Nuclear Power Institute" for short), under the Seventh Academy in the beginning and later moved under the Second Ministry of Machine Building. Led by Director Zhou Shengyang [0719 5110 3152], Peng Shilu, and Huang Xuhua, technical personnel began laying out the overall plan for the nuclear submarine powerplant. They compared a number of different designs. A design plan was then completed. Beginning in early 1965, this institute resumed the preliminary design of the nuclear powerplant. In the meantime, industrial departments have also made progress in the test fabrication of major components and materials for the nuclear reactor, which made resumption of the project possible.

(2) Development of Nuclear Fuel Elements

Nuclear fuel elements are the heart of a reactor. They consist of the fuel core, the cladding, and the structural components. Properties of the fuel elements have a direct impact on the safety and reliability of the reactor. They are therefore a key component of the nuclear submarine powerplant. As early as 1958, the Atomic Energy Institute began the exploration of fuel elements

for a nuclear submarine reactor. In the early 1960s, Shenyang Institute of Metallurgy of the Chinese Academy of Sciences made a systematic study of the fuel element technology. In March 1963, the Second Ministry of Machine Building decided to establish a fuel element laboratory at the Baotou Nuclear Fuel Element Plant. The resources and equipment for studying fuel elements in the Atomic Energy Institute were also moved to the Baotou laboratory to begin research on fuel elements. Subsequently, with close cooperation between the Shenyang Institute of Metallurgy and the Baotou Fuel Element Plant, many technical problems were overcome and test elements meeting the technical standards were developed. Component tests and single rod irradiation tests were conducted in both the experimental heavy water reactor and the swimming pool reactor. The tests were successful.

The fuel rods needed by the model reactor had to be produced on an industrial scale. In August 1967 the fuel element plant began the construction of a fabrication shop for nuclear reactor fuel rods. To speed up the production, the plant made do with old equipment and buildings, and produced fuel rods by a make-shift chemical method. Although the equipment was crude and labor intensive, the manufacturing process ensured a smooth production.

The structure of nuclear submarine reactor fuel elements complex is complex and require sophisticated manufacturing technology. The quality of the fuel elements have a direct impact on tactical performance and safety of the crew. There were very specific quality and technical specifications on incoming raw material, intermediate products, and the finished product. Inspections were carried out rigorously. Under the supervision of nuclear materials expert Zhang Peilin [1728 3099 7207], the technical staff worked with technicians and cadres, and the research staff worked with the design and production staff. The fuel rod fabrication shop was completed and the first batch of fuel elements produced in April 1970. After operating for 9 years in the land-basedmodel reactor, the quality of the fuel element has proved to be excellent.

Fuel Element Cladding Technology

Zirconium has a small absorption cross section for neutrons and can withstand high temperature, high pressure, and water corrosion. It is a good cladding material for reactor fuel rods. The machining of zirconium is an important task in fuel element production. In 1959 the Nonferrous Metals Research Institute produced a number of zirconium alloy materials using high-impurity industrial zirconium sponge. These materials were tested by the Atomic Energy Institute for still water corrosion characteristics. Zircalloy-2 was found to have good corrosion resistance. Later they produced high-quality zircalloy-2 ingot and developed machining methods for zircalloy-2 tubes. In September 1964, the first batch of fuel elements clad with zircalloy-2 were produced. At the same time, the Shanghai Nonferrous Metals Institute produced zircalloy-2 tubes. The Central Military Commission issued a special letter calling for timely completion of the nuclear submarine project. After receiving the letter, the Ministry of Metallurgy constructed a complete zirconium tube production line in its Baoji nonferrous metal processing plant. By 1972, zircalloy-2 materials of different specifications were produced by the Baoji plant, the Shanghai Institute of Nonferrous Metals and the Beijing Institute of Nonferrous Metals. These materials met the requirements of the nuclear reactor fuel elements.

The control rod of the nuclear submarine reactor was made of cadmium. Cadmium, a rare element, occurs together with zirconium in nature. Its extraction is very difficult. Cadmium has a large absorption cross- section for thermal neutrons and can withstand strong irradiation. Since the cadmium-zirconium separation technology was already in hand, cadmium was chosen as the principal material for the reactor control rod. In 1966 the Beijing Institute of Nonferrous Metals produced China's first cadmium ingot. After that, the ingot was extruded into tubes at the Luoyang Copper Processing Plant and rolled into high-quality cadmium tubes by the Shanghai Steel Institute. The task of producing cadmium tubes was later assigned to the Baoji Nonferrous Metals Plant.

(3) Construction of Land Prototype Reactor

Meeting the 1970 target date set by the Central Special Committee for completing the land-based model reactor first required a design for the nuclear powerplant of the submarine. The proposal by the Nuclear Power Institute had a layout that placed the nuclear powerplant in three: compartments the storage room, the auxiliary machine room, and the main machine room. The proposal by the Qinghua University Nuclear Energy Technology Institute had a unitary layout for the power device. After extensive discussion and consultation with experts Qian Sanqiang [6929 0005 1730] and Qian Xuesen [6929 1331 2773] and with industrial departments, the distributed layout plan was chosen. The plan was approved by the Central Special Committee in July 1965. Subsequently, the Atomic Energy Institute quickly obtained results in reactor physics, thermodynamics and hydraulics, material irradiation and corrosion. These results served as reliable data for the design. After completing the preliminary design of the nuclear powerplant, the Nuclear Power Institute began the design of major components of the reactor core. Construction engineering design also proceeded quickly at the Second Design Institute of the Second Ministry of Machine Building. Tasks on equipment and material fabrication in units under the First, Second, and Sixth Ministries of Machine Building and under the Ministry for Metallurgy quickened their pace. In the second half of 1965, construction, design and research personnel moved to the building site of the model reactor and began construction. Shortly after that, the "Great Cultural Revolution"

began and the construction effort suffered severe disruption. Two years after the beginning of construction, only 15.1 percent of the total project had been finished. None of the ten major laboratories planned for the project had been built. These disruptions severely hampered the timely completion of the land-based model reactor.

In order to turn the situation around, the Central Military Commission issued a "Special Memo" in August 1967 to the whole country regarding the assurance of progress in the nuclear submarine development. Nie Ronzheng also stressed repeatedly that the nuclear submarine project can only move its completion date forward and not backward. On 18 July 1968, Mao Zedong ordered the military services to participate in the construction of the land-based model reactor. These emergency measures played an important role in ensuring the completion of the construction. Participants of the project included the Chinese Academy of Sciences, colleges and universities, the Navy, the First, Second, and Sixth Ministries of Machine Building, the Ministry of Metallurgy, the Ministry of Chemical Engineering, Sichuan Province, Heilongjiang Province, and the municipalities of Shanghai and Wuhan. These departments and regions, under the leadership of the State Council and the Nuclear Submarine Leadership Group of the Central Military Commission, assumed and completed research, equipment, and material tasks. The Nuclear Submarine Engineering Leadership Group, under Office Director Chen Youming [7115 0671 6900], effectively organized and coordinated many productive tasks. A number of coordination meetings were held jointly by the Defense Science Commission and the Office of Defense Industries for the research, equipment, and material of the nuclear powerplant. Major technical problems were timely coordinated and resolved by the nuclear submarine engineering equipment technology leadership group. The group consisted of the Navy, the First, Second, and Sixth Ministries of Machine Building, and the Ministry of Metallurgy.

To speed up the construction of the reactor, the Defense Science Commission and the Office of Defense Industries decided to enhance the chain of command. He Qian [0419 6197] of the Second Ministry of Machine Building was appointed the commander and Zhang Zhixin [1728 1807 0207] of the Seventh Academy was appointed the political committee member. The Second Ministry of Machine Building shifted a number of key staff members to the project to strengthen the management of on-site construction. Teams of capable construction workers were drafted from other locations to reinforce the project. The Nuclear Power Institute of the Seventh Academy formed a design team of more than 100 people to work at Laboratory 719. Together they completed the construction design of the model reactor and the technical design of China's nuclear-powered submarine. Meanwhile, the Seventh Academy appointed Peng Shilu to be in charge of the overall design of the nuclear submarine and the land-based reactor, Zhao Renkai to be in charge of the technical design and construction of the main building of the land-based model reactor, Fu Defan [4569 1795 3972] to be in charge of production preparation, testing and post-construction operation management of the land prototype reactor, and dispatched a task force led by Xia Tong [1115 2717] to assist the command department in solving technical problems encountered in the construction. More than 800 technical staff from the Nuclear Power Institute moved from Beijing to the nuclear reactor design base in the Sanxiang region to participate in the installation, testing, and other experimental efforts before the startup. In addition, a full-size, zero-power experimental device and a nuclear power control system testing laboratory were also built for full-scale physics experiments and research. In the installation and testing process, design, testing, and operation personnel, working together to double-check the design, discovered and solved a major technical problem of high residualreactivity. With pride and a sense of responsibility, the 8,000 military and civilian personnel working at the construction site endured the harsh environment of high mountains, a crowded construction site, heat and rain, and pushed the project forward. The Southwest Seventh Construction Office of the Second Ministry of Machine Building and the third engineering region of No. 26 Company finished their respective construction tasks for the main building roof and water supply ahead of schedule. After more than a year of hard work, the ground construction of the land-based model reactor was basically completed at the end of 1969. The Shenyang Water Pump Plant, the Harbin Electric Motor Plant and the Shanghai Boiler Works were responsible for the closed pump of the main facility and the construction of the evaporator. These plants all sent people to the construction site to arrange for equipment installation. After 4 months of hard work, the equipment installation was completed ahead of schedule in April 1970 and the quality of the work was good.

(4) Start of Land Prototype Reactor and Life Cycle Operational Test

The reactor began its test run on 1 May 1979. Problems encountered in the first run were solved by engineers and workers from the First, Second, and Sixth Ministries of Machine Building, the Ministry of Metallurgy, the Navy, and the 17 plants under the Seventh Academy. Test runs went smoothly and test results showed that the engineering quality was superior and the reactor was ready for startup.

The land-based model reactor was an extremely complex, high precision nuclear power system consisting of 26,700 components and equipment. Its quality must be evaluated by actually running the reactor. In order to uncover the problems and to make timely corrections for the benefit of gaining experience in building China's first nuclear submarine, Zhou Enlai approved the startup of the reactor. On the day before the startup, Zhou was twice briefed by on-site leaders and key technical personnel. He also ordered an expert task group to the

testing site to guide the work and to stand by for potential problems. The expert group also made specific requests to the test personnel.

The reactor began ramping up its temperature and pressure on 16 July 1970. At 2 the next morning, the power test began. The reactor was shut down safely at 10:53 in the evening on 30 July 1970. During the test period Zhou made several telephone calls to check on the test situation, asking repeatedly that the test be done carefully and that all the data be acquired. The testing crew worked day and night for 15 days and tried out the various systems of the reactor. They conducted 131 measurements for the physical, chemical, thermodynamic, hydraulic, shielding, dosage, stress, vibration and noise characteristics of the reactor. All the necessary data were obtained. Test results showed that the quality of the design, manufacturing and installation was excellent. The reactor also performed well in control safety, stability, and protective adjustment.

A second stage power up experiment was then conducted to further evaluate the design power of the reactor and the design horsepower of the main turbine, to improve the shielding structure, and to characterize the dynamic performance. The second stage test lasted for a total of 27 days. Test results showed that China's first nuclear submarine reactor was a success. The reactor and its power components can not only be operated safely in stable conditions, but can also assume heavy load variation in a battle situation. The movement performance was superior and met the tactical and technical requirements. These tests served as a sound foundation for the navigation test of China's first nuclear submarine. In the meantime, shortcomings were found in the power device, which served to improve thedesign of future submarines. In the 9-year operation of the land-based model reactor from July 1970 to December 1979, a total of 530 tests were conducted. The main performance characteristics of the nuclear powerplant were thoroughly understood and a complete set of data was acquired for the reactor core over its service life. The reactor was shut down in December 1979 and the cover was removed to inspect and evaluate the reactor. The operation and inspection results showed that the first nuclear submarine power device designed and built by the Chinese themselves was a success. Reliable data were collected for the design of a new generation of nuclear powerplant. The test also produced valuable personnel training and accumulated a vast amount of experience.

(5) Construction of China's First Nuclear Submarine Powerplant

The performance specifications of China's first nuclear submarine power device were identical to those of the land-based model reactor. They were designed and built simultaneously. This approach was very important to the success of the first attempt in building and installing the submarine nuclear reactor. However, because of the tight schedule, there were a certain amount of exploration in the design and manufacturing of nuclear powerplant. The procedure specified by the Central Special Committee was rigorously followed; that is, installation of the reactor on the submarine began only after the land-based model reactor reached full power operation. To ensure proper installation, a full-scale wooden mock-up was designed, built, and installed jointly by the Nuclear Submarine Manufacturing Plant, Laboratory 719, and the Nuclear Power Institute. By so doing, problems in the manufacturing and transportation of the installation equipment were discovered and resolved at an early stage. The nuclear reactor was successfully installed on the submarine on 26 December 1970. The success was a result of a joint effort by the technical staff, workers, and cadres in the research, design, and installation departments and by the Navy commander.

Dock tests of the first nuclear submarine began in April 1971. Test procedures similar to those used on the land-based model reactor were followed in the cold run of the primary circuit auxiliary system of the nuclear powerplant. The same was done for the water pressure test of the main heat carrier system and the second circuit test run. At the end of April the active zone of the reactor was hoisted into the pressure vessel and the reactor body and top components were installed. At the end of May the reactor safely achieved cold critical state. The hot critical state was reached at the latter part of June. Some malfunctions occurred in the process of raising the temperature and pressure of the reactor and the primary circuitry but these malfunctions were quickly eliminated. On 1 July, the reactor power was raised, the steam generator started the system auxiliary and the gas turbine began generating electricity. This was the first time that a nuclear reactor had produced electricity on a Chinese submarine. The reactor performance met the design target and satisfied the service requirement of the submarine. The nuclear reactor was capable of propelling the submarine.

The series of dock tests for China's first nuclear submarine was completed on 23 August 1971. This was followed by navigation tests. The equipment and systems were found to function properly during the navigation tests.

On 3 February 1972, in the 16th cruise test, the steam generator of the main unit malfunctioned upon switching from low speed to high speed. Technical staff and workers risked high temperatures and radiation overdoses to enter the reactor module for repair. They showed fearless dedication. Engineer Li Yichuan [2621 1355 0278] of Laboratory 719, after falling ill due to exhaustion, died of a heart attack at a young age at the reactor site. To explore the cause of the malfunction and toevaluate the reliability of the submarine and its systems, Chairman Mao signed a telegram on 12 August to authorize a long cruise test. In the last run of the navigation tests, the steam generator malfunctioned again. The submarine was then serviced in the plant. The water quality control system was improved while the steam generator was being replaced. The navigation tests resumed in January to April 1974, for exploratory runs.

The nuclear submarine went through 20-odd navigation tests, the reactor logged several thousand hours of operation, and the accumulated mileage was thousands of nautical miles. The entire ocean navigation test showed that China had succeeded in developing its own nuclear submarine power device.

(6) Long Cruise Test

The long cruise test was conducted after the submarine was delivered to the Navy and put into service. The purpose was to test the reliability of the submarine and the equipment on board on long cruises in the ocean. In early 1980, a long cruise test was planned by the Defense Science Commission, the Office of Defense Industries, and the Navy. The test was divided into two steps: first there would be a 31-day cruise followed by a longer one.

The primary concern in the long cruise was the quality of such equipment as the stream generator. In preparing for the extended cruise, the Navy organized a joint on-board inspection of the quality of the steam generator. The inspection was conducted by the nuclear submarine fleet, the nuclear submarine manufacturing plant, Laboratory 719 and the naval representative stationed at the plant. In mid-1980 a team of experienced specialists rushed to the test site and made a rigorous inspection of the submarine after a few hours of high capacity sailing on the ocean surface. They concluded that the steam generator functioned normally and could continue to run.

At 7 AM on 16 November 1981, Captain Li Jinkui [2621 6855 1145] started the nuclear submarine under the command of Deputy Commander Qu Zhengmu [2575 2182 3664] of the North Sea Fleet. This test lasted 31 days and covered several thousand nautical miles. The cumulative underwater sailing was 25 days, or 80 percent of the entire journey. The longest submerged sailing was 330 hours over a distance of 1,000 nautical miles. The test showed that the main power system functioned reliably and the steam generator functioned without any problem. All the major electrical components operated normally. The two main converter units successfully pulled back after five intentional reactor shut-downs. This ensured the safe startup of the reactor in emergency situations. The integrated air conditioning system worked well and ensured normal living conditions for the crew. Underwater maneuverability was very stable. From 25 November 1985 to 18 February 1986, the nuclear submarine conducted the maximum self-sustainability test. The purpose of the test was to conduct a general evaluation of the tactical and technical performance of the submarine, the reliability of the systems over extended periods of time, and the ability of the submarine to handle long periods of underwater activity. This test was directed by Deputy Commander Yang Xi [2254 3886] of the Navy Submarine Base and submarine commander Sun Jianguo [1327 1696 0948], and was conducted in the Yellow Sea and East China Sea training ground, as specified by the General Staff. The nuclear submarine sailed in deep water for 10 days and traveled a distance equal to the perimeter of the earth at the equator. Most of the time the submarine was under water and the longest continuous underwater journey lasted 25 days. The experience was described as the "underwater long march." This test set a number of records in Chinese submarine history, including the longest navigation time, the longest submerged navigation, the longest range, and the highest underwater sailing speed. With the exception of the torpedo launcher and the rescue system, all the mechanical devices on the submarine were tested. Following the test plan, 63 evaluation tests were conducted and a complete set of data was acquired. The tests proved that most of the mechanical devices on the submarine functioned reliably. The main power device ran for a total of several thousand hours and the reactor's cumulative full-power days numbered several tens. The reactor, the main pump, and the main turbine system functioned smoothly and reliably without any problems. There were no leaks in the primary circuit. The electrical system worked well. The two gas turbine generators were generally run in parallel to assure electricity supply. The main converter unit, the intermediate-frequency units and the 200 electrical devices all worked reliably. The startup was readily implemented and the timely switch-over ensured emergency electricity supply. Dosage monitoring results of the cabin space showed that radiation dosage and pollution remained in the standard allowable range. The long cruising test was not only the ultimate test for the equipment systems, but also the ultimate test for the stamina and willpower of the crew. For several tens of days under the sea, the crew endured high temperature, high humidity, noise, polluted air, fatigue, insomnia, and anorexia. In the last 2 days of the journey, a number of crew members went into shock due to extreme fatigue, but they all persevered and miraculously created the "underwater long march."

Section 3. Depth Test of Nuclear Submarine

The depth test of the nuclear submarine was mainly an evaluation of the overall performance and battle ability of the submarine. The test included a deep dive, underwater full speed, and torpedo launch in deep sea. The scale of the test was large and involved many aspects. The organization of the test was complex and the difficult test carried a certain level of risk. It was a comprehensive examination of the research, design, construction, and crew operation of the nuclear submarine and its weapons systems.

In 1979 the State Council and the Central Military Commission issued the depth-testing order for the nuclear submarine. To fully prepare for the test, the Navy worked with the China Shipbuilding Company and made in-depth investigation of the depth test. Issues addressed included project coordination, organization and leadership, division of work assignments, and budget allocation. After the project was reviewed by the General Staff Department and the Office of Defense Industries, a proposal entitled "Depth Test of the

Nuclear Submarine" was submitted to the State Council and the Central Military Commission. On 16 November 1987, the proposal was approved and the depth test of the nuclear submarine entered the implementation stage.

(1) Test Preparations

In June 1987, a nuclear submarine deep-water testing leadership group (or depth-test leading group) was formed. The group was led by Deputy Commander Zhang Lianzhong [1728 6647 1813] of the Navy and was under the direct supervision of the General Staff Department and the Defense Science and Technology Commission. Other members of the group were the State Planning Commission, the State Economic Commission, the Defense Science and Technology Commission, the China Shipbuilding Company, the Ministry of Nuclear Industry, the Guangzhou Military Region, and the Guangdong Province.

The depth test leading group adhered to a meticulous and careful approach to guard against political or technical incidents that could lead to loss of life or the vessel during the test. Safety was the top priority. The group reviewed test plans, test items and the primary network plan. The various departments have also established or improvedcorresponding organizations and formulated secondary network plans for their respective assignments. The tasks and responsibilities were clearly assigned and the effort was a cooperative one. Based on the primary network plan, the various specialty groups reviewed the design and construction quality of the submarine and prepared for the testing, monitoring, maneuvering, rescuing and logistic protection.

The following measures were taken to make sure that the vessel left port without any problem or potential risk.

A. Quality Review

Comprehensive reviews were conducted by Laboratories 719, 703, 704, 705, and 725, and by the First Academy of the Ministry of Nuclear Industry. Review items included the overall performance of the submarine, the strength of the submarine structure, the systems installed on the submarine, the design criteria and parameters, standards, and codes for the reactor and the main frame. Also reviewed were design calculations, technical conditions, construction charts, modifications and discrepancy handling records. Technical problems revealed in the review were resolved. Starting from raw materials, the Nuclear Submarine Manufacturing Plant and the military liaison at the plant conducted ultrasonic and X-ray flaw detection for the weld seams of the submarine hull and for the valve and tank systems. The inspection and flaw detection were repeated for the external pressure tank and for the pump systems. Electrical equipment and onboard systems were re-checked. Manufacturing quality problems revealed by the inspection were resolved. For problems discovered in the evaluation, the diving test leading group made its decisions based on the principle of upholding technical quality and also taking into account practicality. For example, there were more than 70 rubber shock-absorbing tubes in the seawater system in the submarine. These tubes were manufactured before 1981 and had exceeded their service life. They were therefore considered a safety hazard for the diving test but to replace them would require 800,000 yuan and 6 months' time. To resolve this problem, the technical group inspected all the tubes along with the pump pressure of the seawater system and conducted on-land simulation of pump pressure for adverse conditions. The results showed that quality was assured and a decision was made to continue their use. Another problem was the switch- in time of the auxiliary pump when the main pump loses power. This problem was investigated by Chief Designer Zhao Renkai, Deputy Chief Engineer Chen Weiben [7115 4850 2609] of the First Academy of the Ministry of Nuclear Industry, and other reactor engineers. They inspected the control rod position and the technical status of the reactor, and performed extensive analysis using the experimental data obtained on the land-based model reactor and the first submarine. They concluded that the reactor safety would not be jeopardized if both pumps lost Power and an auxiliary pump was switched on within 1.8 seconds.

B. Nuclear Submarine Maintenance

On 22 December 1987, the test submarine entered the yard for some modification and equipment addition. Strain gauges were installed on the submarine hull and some scheduled maintenance was performed. The workers had to complete 497 jobs in freezing temperature under a tight schedule. The Nuclear Submarine Manufacturing Plant adjusted the production line for civilian items and moved the submarine indoors for better working conditions. With appropriate measures, the schedule was met. The technical staff, workers, and cadres worked consciously and paid attention to every detail to ensure a smooth depth test for the submarine.

C. Preparation of the Testing and Monitoring Systems

The preparation was conducted by Laboratories 702, 719, and 705, the Navy's South Sea Depth Testing Site, and the First Academy of the Ministry of Nuclear Industry. Measurement and monitoring systems prepared for the submarine included stress-strain monitoring systems, acoustic positioning and velocity measurement systems, nuclear radiation dosage monitoring systems, noise measurement systems, submarine motion measurement systems, torpedo launch pressure and muzzle velocity measurement systems, and torpedo trajectory measurement systems. Scientific data were accumulated for evaluating the safety and performance of the submarine.

D. Crew Training

Following standard regulations, the submarine base trained the crew for underwater accidents, emergency surfacing, emergency reverse, and reaction to longitudinal inclination. Chief Electrician Yao Jinquan [1202

2529 3123] organized a mock exercise on the simulator in Laboratory 719 for deep dives and high-speed cruising. Preparation for incidence and reaction to various incidence were made. This training formed a good foundation for proper operation and safe testing of the submarine.

E. Rescue and Protection Exercise

The Navy navigation and protection department organized the rescue departments of the North Sea, East Sea, and South Sea fleets and the Naval Medical Institute to formulate rescue and medical protection plans, prepare rescue equipment, form rescue teams, and conduct rescue exercises.

In addition, the No. 750 test site of the China Shipbuilding Company and the Navy's South Sea depth test site and other units also made extensive preparations in the areas of torpedo, torpedo technology base, target, measurement systems, and communications.

(2) Implementation in the South Sea

In March 1988, the depth test leading group inspected the preparations, assigned the duties for the South Sea implementation, and named Deputy Commander Qu Zhengmu of the South Sea Fleet as the chief commander. Four deputy commanders were named: Deputy Naval Chief of Staff Shi Tianding [4258 1131 1353], Deputy Manager Huang Pingtao [7806 1627 3447], Deputy Chief of Staff of the North Sea Fleet Wang Shouren [3769 1343 0088], and Deputy Director of Naval Logistics Wei Bochang [7614 2679 7022]. Commander Yang Xi of the submarine base was named the commander of the submarine.

In April 1988, the submarine arrived at Zhanjiang harbor. Shortly thereafter support vessels and personnel also arrived. The various specialty groups made arrangements for their respective testing tasks. An action plan, an implementation plan, communications procedure and a signal chart were organized and formulated under Deputy Chief of Staff He Chunlian [0149 2504 6647] of the South Sea Fleet. These documents specified implementation procedures and methods. The technical group led the participants in a re-check of the technical condition of the submarine and readied the mechanical equipment and monitoring apparatus. The political group and the logistics group, with the help of naval bases in Guangzhou and Zhanjiang, the Guangdong Province, and the municipality of Zhanjiang, took care of security, water, electricity, and other matters. All pre-sailing preparations were completed in 2 weeks.

The deep dive test was to find out the deepest dive depth of the submarine; it was the heart of the three depth tests and was also the riskiest. In order to ensure safety, the leadership group decided to take a step-by-step approach.

Stage I was a 180-meter preparatory dive. At 1600 hours on 20 April, the nuclear submarine left the harbor and sailed 210 nautical miles to the test zone. At 900 hours on 21 April, the submarine dived to a depth of 193 meters. The preparatory dive was handled properly and the equipment worked well. Data were collected by all six monitoring stations. The test revealed excessive strain readings on the strain gauge exterior to the broadside. The malfunction was eliminated by using shielding and compensating measures.

Stage II was a deep dive test. Because of the risks involved, it was decided that a crew of 176 would participate. Deputy Commander Wang Shouren took command and Huang Xuhua, Wu Tingguo [0702 1656 0948] and Xu Binghan [1776 4426 3352] were in charge of technology. The submarine sailed on 28 April. While at sea, improper filling pressure of the adjustment water tank caused damage to the seal of the hatch cover. Team leader Xu Yong [1776 0516] led workers into the dosage zone above the reactor and repaired the damage; the deep dive test proceeded normally. At 0920 hours on 29 April, there were some problems with underwater acoustic communications after the dive. The submarine surfaced then to periscope depth. Wang Shouren and Shi Tianding, who was commanding the rescue ship, decided jointly that the submarine commander should decide whether to continue the dive if the communications were interrupted again. At 1113 hours, the submarine dived again. At a depth of 230 meters, 11 outbursts of noise were heard in the submarine and there were 19 leaks. Some support angle iron buckled. Commander Wang Fushan was coolly in command and the crew members all performed their jobs well. Inspectors carefully watched the vessel. When the submarine reached maximum working depth, the hull did not emit any more noise and the leaks did not worsen. The dive continued. At 1203 hours, the depth gauge in No. 2 compartment indicated that the submarine had reached maximum depth and set a record for the Chinese Navy in deep diving. The deep dive test results showed that the submarine hull structure and connection systems were safe and reliable. All the mechanical devices functioned normally and the test was a success.

Stage III was a test for flank speed under water. Full speed was a severe test for the submarine's performance, the mechanical devices on-board, the technical level of command and control, and the ability to deal with emergencies. To ensure safety, it was decided that the following people would be in charge of technology: Zhao Renkai, Chen Weiben, Wang Daotong and Deputy Director Zhang Jinlin [1728 6855 7792] of Laboratory 719. When the reactor was started up to generate steam while the vessel was docked, deputy team leader Dong Youjing [5516 2589 4842] of the Nuclear Submarine Manufacturing Plant discovered that the discharge valve under the evaporator malfunctioned. Upon inspection it was discovered that the threads of the bolt connecting the valve body and the valve seat were severely damaged. The connection was quickly welded and an accident was averted.

The submarine left harbor on 12 May and conducted high-level baseline tests while sailing toward the test zone. When the propeller speed was increased from 125 rpm to 183 rpm, the control panel started to vibrate vigorously, but all the mechanical devices, nuclear powerplant, and instruments and meters worked normally. At 0701 hours on 13 May, the submarine entered the test zone. At 0951 hours, the submarine dived to the starting position and began speed measurement tests after two practice runs with support vessels. When the propeller speed was increased to 198 rpm, the submarine reached full power and continued to function normally. At this time the reactor power was less than 90 percent and there was still some power in the main unit intake. After some discussion, the experts on-board and the commander decided to increase the speed by 2 rpm. When the chief electrician reported 200 rpm, the captain once again ordered steady operation and mechanical checks; the speed was then reduced. At 1316 hours, the test was concluded and the monitor stations acquired real-time data. The speed of the nuclear submarine reached the design value and the main unit had some spare power. The reactor power still had considerable reserve. The overall thermal efficiency of the power device was higher than the design value by 2 percent. The test was a success and proved that the nuclear powerplant, the electromechanical devices on board, and the equipment and meters all functioned reliably. The reactor shielding met expectations and ensured the safety of the crew.

Stage IV was a torpedo launch test at deep depth. Supporting vessels participating in this test numbered 12 and the diving submarine had a crew of 192. The organization and command of the test were complex and the requirements on hydraulics and weather were high. It was the largest test involving the most personnel and equipment in China's history of submarine torpedo launch. As the departure date approached, the weather deteriorated. Overcoming great difficulty, personnel of the South Sea naval depth test field successfully deployed the measurement systems. The test commander made a bold decision to finish the test before the arrival of the storm. The fleet arrived at the experimental zone at 0515 hours on 25 May. The command ship, measurement ship, sound source ship, and support ships all took up position and practiced with the submarine. At 1059 the first torpedo was launched, followed by three more launches. Test results showed that the torpedo launching device and other systems functioned normally and safe launch at great depth was ensured. The torpedo weapon system met the precision requirement. After the auto-guidance system captured the target, it tracked the target automatically. The torpedo was also capable of relocating and re-tracking the target.

The success of the depth tests indicated that China had completed the research and development of its first nuclear submarine. These tests proved that the development was a success, the construction quality was sound, and operating skills were superior. The submarine was now combat-ready and had generated vast scientific data and valuable experience for nuclear submarine warfare and for the development of the next-generation nuclear submarine. It was an important chapter in China's naval weaponry development.

Section 5. The Submerged Launching Test of Submarine-Surface Missile

The underwater launch test of a submarine-to-land guided missile is a three-stage process. First, a submerged launching test is conducted from a conventional submarine, then, the test is conducted on a nuclear submarine, and a final test is conducted on a nuclear submarine.

(1) Advance Preparation

To meet the needs of testing a submarine-surface missile on a nuclear submarine, the Central Military Commission decided in the late 1960s that the Naval Test Base should be in charge of building the submarine-to-land missile test range. The general staff and the Defense Science Commission organized relevant personnel in the Navy and in industrial ministries in March 1968 to conduct field surveys and site selection. The activity was led by Deputy Commander Bing Ye [0393 6851] of the Naval Test Base. In 1971 the Central Military Commission approved the southern Liaoning test site. After 8 to 9 years of hard work, China built the technical position, the launch position, the test command post, the safety control center, the optical, radar, and remote-sensing stations, the communications facility, the dedicated railroads, docks, cranes, and hydraulic and meteorological facilities. The target zone in Gansu was also built. While building the test site, a submarine-surface missile testing department was established in March 1977. The department was under the leadership of the Naval Test Base and was led by Commander Yang Honggui [2799 3163 6311] and political committee member Sun Liu [1327 0362].

A closely coordinated effort ensued, with participation by the Defense Science Commission, the Navy, and the development departments. After years of work, various measurement and monitoring facilities were developed, modified, and put into service. A communications and signal transmission problem was encountered in the course of the test in the early 1970s. To solve this problem, Niu Shunchang [3662 7311 7022] of the test base worked with Fan Chunsheng [5400 2504 3932] of Laboratory 19 of the Seventh Academy and developed a simple, convenient and practical communications raft. A wind-resistant raft equipped with special antennas and a tracer tube frame served as a carrier. Communications with the submarine were conducted through sealed electrical cables attached to the steel cable. After repeated submerged launching tests and continuous improvements, the unique communications raft has become an effective means for solving communications between the submarine, the coast base, the ocean surface, and the air. Its main functions were to transmit timing signals and the countdown data of the launch so that land-based

equipment could have aiming data and could estimate the approximate position of the submarine underwater.

In 1980 China established its deep-water survey fleet and acquired the ability for surface monitoring of the reentry section of the carrier rocket and recovery of the data capsule. In the meantime, safety concerns of important cities along the westward launch path of the submarine-to-land missile was also considered. The Defense Science Commission and the Navy thoroughly investigated the problem and, with approval of the Central Military Commission, decided to change the launch direction. The target zone in northwest China was scrubbed and the end zone task was assigned to the survey ship base. Necessary modifications of the head zone monitoring system were made for the launch direction change and for the communications and measurement facility. After 3 years and many obstacles, test preparations were completed.

(2) Launch Test of Submarine-Surface Missile From Conventional Submarine

China's first submerged launching of a submarine-surface missile was conducted on a modified conventional submarine. The difficult test involved many units and backup forces. To enhance the leadership organization and the coordination of the task, an ocean test leadership group was established in 1980. The group leader was Navy Deputy Commander Yang Guoyu [2799 0948 1342] and the deputy group leader was Deputy Director Ma Jie [7456 2212] of the Defense Science Commission. The leadership group formed an office, which was headed by Deputy Director of the Navy Equipment Technology Department. In 1981, a system of chief engineer for testing was established. The chief engineer was Huang Weilu [7806 4885 4389] who was the chief designer for the submarine-to-land guided missile. Deputy chief engineers were Huang Xuhua [7806 2485 5478], Shen Rongjun [3088 2837 7486], and Xie Guolin [6200 0948 3829]. Huang was the chief engineer for the submarine, Shen was the deputy director of the measurement and communications laboratoryof the Defense Science Commission, and Xie was the chief of staff of the naval submarine-to-land missile test department. In March 1982, commands were established for the head and end zones. Commander of the head zone was Tian Zuocheng [3944 0155 2052], commander of the naval test base. Deputy commanders were Zhou Cheng [0719 6134], Ma Lixin [7456 4539 2946], Huang Weilu, Huang Xuhua, Yang Honggui [2799 3163 6311], and Li Wenfa [2621 2429 4099]. Zhou was deputy commander of the naval test base, Ma was the deputy commander of Lushun base, Huang Weilu was the chief designer of the missile, Huang Xuhua was chief designer of the submarine, Yang was commander of the end zone, and Li was the submarine dispatch leader. Commanders of the end zone were Tian Zhenhuan [3944 2182 3883], Jin Min [2529 2404], Liu Honglu [0491 3163 7120], and Meng Xiancheng [1322 2009 6134]. Tian was the survey ship base commander under the Defense Science Commission, Jin was the deputy chief of staff of the East Sea Fleet, Liu was the deputy commander of the Zhoushan base, and Meng was the deputy chief of staff of the survey ship base. To ensure successful execution of the test, the Second Academy organized a test team, which was headed by Wang Zhaoqi [3769 0340 7784] and was sent to the test site.

The test was organized and commanded by the command office of the Defense Science Commission. Communications and information exchange between the head zone and the end zone were implemented by the General Measurement and Communications Office of the Defense Science Commission. The Weinan monitor and control center was responsible for the signal exchange between the head and end zones.

Preparation in the head zone proceeded simultaneously on four fronts: technical position, launch position, control and communications, and rescue and alert. The technical position was led by Zhou Ganlin [0719 3227 2651], director of Laboratory 201. Zhou came up with a staggered procedure which allowed the testing of three fires instead of two. The technical position formulated detailed operating procedures, checked and calibrated hundreds of ground testing equipment, solved technical problems, ensured the quality of the missile and completed the test mission.

The test mission was organized and conducted by the submarine commander Shi Zunli [4258 1350 4409] and other participating units, including the submarine-surface missile test field. The following tasks were completed in the test: submarine crew training, experimental submarine test run, calibration of instruments, installation and adjustment, compatibility testing, communications raft testing, departing with missiles, launching exercise, coordination exercise, and underwater rescue training. The control and communications equipment was stretched out over a very long distance. It was a formidable task to put measurement, guidance, remote control, computer hardware and software, communications and data transmission equipment together and form a real-time measurement and processing system. The technology was very complex and the time constraints were stringent. In the end, difficulties were overcome and the missions were accomplished owing to the hard work of many technical and operating staff under the leadership of Deputy Commander Gu Shouren [7357 1343 0088] of the test field.

In carrying out the test mission, the test field also organized flight calibration of the measurement system, communications and transmission joint exercises, interference tests, and signal conditioning for the head and end zones. After 16 dynamic calibrations, the accuracy and reliability of the measurement system was verified and the entire system was adjusted to its optimal state. Deputy Secretary Zhang Aiping of the Central Military

Commission inspected the system calibration and expressed his compliments to the skill of the crews in a plaque penned by himself.

The Lushun base was mainly responsible for providing coverage of the ocean with 58 vessels for surface security, escort, rescue, and protective missions. The crews carefully studied the implementation plan, made specific assignments, and repeatedly practiced the rescue exercises.

In the early morning of 7 October 1982, the test proceeded in a tense but orderly fashion based on the regional command procedure. In the command post, Command Group Leader and Deputy Chief of Staff Wang Huike [3769 1920 1952] of the test base, announced "battle stations" and each post carried out the pre-launch preparations. At 1500:14:01, the first submarine-surface missile was launched. The launch was normal but the missile tumbled out of control shortly after ignition and self-destructed in the air. Chief Designer Huang Weilu led the technical staff in the investigation of the cause for the self-destruction and took preventive measures for the second firing. At 1500:00:01 on 12 October a second missile was successfully launched. Congratulatory telegrams came from the Party Central Military Committee, the State Council, and the Central Military Commission. The successful launch of China's submarine-surface missile was a major accomplishment for the technical personnel engaged in submarine and missile technology.

(3) First Launch Test of Submarine-Surface Missile From a Nuclear-Powered Missile Submarine

Submerged launching of a model missile was conducted on a nuclear submarine. This test was conducted after a series of land-based tests and submerged launching of model missiles from a conventional powered submarine. The main purpose was to test the launch controllability of the guided missile, the real-time operation accuracy and reliability of the launch system, and the stability and reliability of the nuclear reactor during the launch. This test was organized by the naval test base and participated in by more than 20 units, including 49 sorties by various vessels and three helicopter sorties. The technical leader and coordinator was Laboratory 19 of the Seventh Academy. The test began on 8 March 1984 and ended 28 April 1984. A total of four model missiles were launched in the Bohai region. Test results showed that the launch system was designed properly and functioned successfully. The controllability of the submarine was excellent and satisfied the launch requirements. The command was accurate and the operation was skillful. The entire test was conducted according to the master plan. The only exception was that hydraulic and meteorological conditions at the time did not allow testing under high wave conditions. A complete set of test data was acquired and the anticipated goals were met.

The first submerged launching of a submarine-surface missile had been made from a nuclear powered submarine. The main purpose of the test was to evaluate the overall performance of the entire weapon system and to assess the tactical and technical level of the system.

The test was characterized by the broad participation of units and personnel. Stringent requirements were set for the safety of the missile flight zone. When a missile is launched from under water, aiming and target acquisition are very difficult. The water and weather conditions are constantly changing. High accuracy is essential for underwater positioning and aiming, and for real-time transmission of signals and count-down data. The underwater stress environment is very complex and the space in the submarine is very cramped. Compared with land-based launch tests, this test had its unique complexity and difficulties.

In May 1985 the Defense Science Commission and the Navy heeded the decision of the Party Central Committee, the State Council, and theCentral Military Commission and issued an order to participating units to conduct submerged launch tests for guided missiles from a nuclear submarine. A test organization was formed and tasks were assigned. Command posts were established in the head zone and end zone. The head zone formed a chief engineer group that consisted of Huang Xuhua, Zhao Renkai and Zhang Ganlin and led by Huang Weilu. Under the unified leadership of the command department, the chief engineer group was given the responsibility of research and coordination of major technical problems.

There were 139 units directly participating in the test mission in the head zone. There were 42 major pieces of measurement equipment, 24 pieces of postprocessing equipment, 245 communications devices, 48 vessels, and three aircraft.

In mid-September, final preparations were completed by the technical position, launch position, monitoring system, the Navy, and the Air Force. The effort was led directly by the head zone command department.

On 28 September, the guided missile nuclear submarine conducted its first underwater launch. The missile broke surface and climbed, but before long tumbled in the air and self-destructed. Two more missiles were launched subsequently and both failed. Although the test failed, the submarine and the powerplant functioned satisfactorily. Complete data were acquired for further study of the underwater stress environment experienced by the missiles. These data were very valuable.

After the test, a series of malfunction analysis meetings and special topics conferences were held by the Defense Science Commission, the Navy, the Ministry of Aerospace, the China Shipbuilding Company, and the Ministry of Electronics. Together with analysis, the Ministry of Aerospace also conducted simulation experiments to reconstruct the malfunction. Tests were made to assess the stress experienced by the instruments on the missile.

Vibration tests were conducted for the instrument module, and compression ratio tests were also made for the underwater separation of the tail cone. In addition, with the approval. of the Defense Science Commission and the Navy, a second submerged launch test was conducted with a model missile from the nuclear submarine. With a series of studies and tests, the cause of the malfunction was basically understood. Effective and comprehensive measures were taken for the next test.

Volume II

Chapter XVI. Anti-Ship Missiles

Anti-ship missiles are guided missiles launched against surface vessels from the water surface, under water, air, and land. They include ship-to-ship, submarine-to-ship, air-to-ship and shore-to-ship missiles. An anti-ship missile is comprised of a missile, fire control system, launch pad and ground equipment. Because of advantages such as high maneuverability, accuracy, penetration capability, and high destructive power, the anti-ship missile has become an important weapon at sea. China began to develop anti-ship missiles in the late 1950s. The development has gone through several stages, such as duplication, modification and design of shore-to-ship and air-to-ship missiles, as well as the development of second-generation anti-ship missiles. Technologically, it has advanced from subsonic to supersonic, from liquid fuel engines to solid fuel engines and ram engines, and from single parameter guidance to multiple parameter guidance. The second-generation anti-ship missiles developed in the late 1980s are approaching or are at world class level in terms of major strategic and tactical characteristics.

Section 1. Construction of R&D Institutions and Test Base

(1) Construction of R&D Institutions

On the basis of the instruction of the Chinese Communist Party to strengthen defense and to meet the need of the Navy of the Chinese Liberation Army, China began to establish research organizations and construct test bases for the development of anti-ship missile systems.

I. Establishment of R&D Development Organizations

In December 1959, on the basis of an agreement between China and the USSR, the latter supplied a number of sample anti-ship missiles, along with some technical data, to the Chinese Navy. As the Fifth Research Academy of the Ministry of Defense had just been established, it did not have the capability to develop guided missiles. The government decided to let the design department of the Fifth Research Academy in charge of the overall technology to duplicate the missiles in factories under the jurisdiction of the Ministry of Aerospace Industry and other relevant organizations. Under the coordination of the Office of Defense Industry and the National Defense Science Commission, the entire country was organized to duplicate anti-ship missiles by combining research, design, and production. Technology associated with research, design and production was rapidly obtained through this duplication effort. Since the Nanchang Aircraft Company had successfully copied several Russian aircraft, in order to speed up the development of anti-ship missiles, in March 1960 the First Machine Building Ministry decided to set up the 40th Office at the Nanchang Aircraft Company to be responsible for the duplication of anti-ship missiles. It constructed the largest air-conditioned missile assembly and test facility at the time and it was China's first ship-to-ship missile production line. In April of the same year, the National Defense Science Commission decided to establish the Fourth Total Assembly Department at the First Branch of the Fifth Research Academy to be in charge of the research and design of anti-ship missiles. Its primary mission was to collaborate with various industries to duplicate and reverse engineer anti-ship missiles and to get a grasp of the design concept and method associated with these missiles.

In the early 1960s, the government was temporarily short of money. In order to concentrate our effort, the Central Military Commission decided to copy the "Po-15" [TN: Probably the Soviet SSN-2A Styx] ship-to-ship missile as the starting point of anti-ship missile development in China. The production was done at the Nanchang Aircraft Company. The Fifth Research Academy sent people to the Nanchang Aircraft Company to deal with problems associated with design and production techniques.

In January 1965, the Seventh Machine Building Ministry reorganized the Third Branch of the Fifth Research Academy to form the Guided Missile Design Academy (i.e., the Third Research Academy) to undertake the tasks of design, construction, and pilot production of complete missile assemblies and various sub-systems. The director of the academy was Lin Yi [2651 3015] and the Party Secretary was Yu Wenren [6735 2429 0117]. The establishment of the Third Research Academy was very helpful to the overall preparation and implementation of plans for the development of anti-ship missiles. Coordination of technical resources was better organized and advanced research was strengthened. However, our capability in prototyping and production was still lacking. In April of the same year, the State Council decided to pull a number of factories and research institutions from the Seventh, Third, Fourth and Fifth Machine Building Ministry and put them under the Third Research Academy to create an entity that combined anti-ship development with production. This laid down a solid foundation for the development of anti-ship missiles in China. Since then, in addition to completing the duplication of ship-to-ship missiles in collaboration with the factory, the Third Research Academy also began to develop new anti-ship missiles concurrently.

As the Third Research Academy was established, the Seventh Machine Building Ministry also began to build anti-ship missile development and production bases in third line areas such as Sichuan and Hubei. In 1970, the development and production facilities under the Third Research Academy and the third line were placed under the control of the Navy. The director was Yu Xiaohong [0060 4562 5725] and the political commissar was Gui Shaobin [2710 4801 1755].

In November 1977, the Third Machine Building Ministry and the Eighth Machine Building Bureau approved the establishment of a ship-to-ship missile design institute at the Nanchang Aircraft Company. Its primary function is to provide technical guidance to the development of ship-to-ship missile assemblies and sub-systems. During this period, the Third Research Academy had gone through several organizational changes. However, considerable progress was made in its research organization and experimental facilities. By 1980, it had become an academy with considerable capability in the design, prototyping and pilot production of anti-ship missiles. It is an anti-ship missile development and production system centered in Beijing with facilities in Jiangxi, Shenyang, Sichuan, and Hubei. It has more than 10,000 employees and has developed more than 10 different models of anti-ship missiles. The development of anti-ship missiles in China followed the path of import, duplication, improvement, and innovation. By sticking to the basics, we continue to develop and improve existing models to enhance their capabilities. We work hard to track new technology to strengthen our technical reserve in order to maintain the momentum of continuous development.

(2) Construction of Test Facility

In order to meet the testing requirements for development and production, there is a need to construct a national missile test range to test the quality of missile systems under near battlefield conditions. The test firing of anti-ship missiles involves a large number of models of different trajectory ranges and carrier rockets and requires coordinated action on land, air, and sea. It is more demanding in terms of organization, command, coordination, technical protection, and safety control.

In January 1958, the Central Military Commission appointed Vice Commander of the Navy Luo Shunchu [5012 5293 0443] to organize a team to survey different sites along the coast with some Russian experts. On 3 March of the same year, the Secretariat of the Chinese Communist Party approved the construction of an over-water test range in Liaoxi as a part of the Northwest Missile Test Range. In March and April, the Chinese and Russian technical team, led by Yang Guoyu [2799 0948 1342] and Sun Liangping [1327 0081 1627], surveyed the site in Liaoxi to pinpoint the land launch sites, technical positions, test command center, optical measurement station, telemetry station, communications center, and test vessel port. After the Russian experts presented a proposal, the engineering design was completed by the Naval Engineer Department under the Special Engineering Corps Command. A construction team of more than 1,500 people was assembled by deploying people from the Navy, Railway Corps, Jinan Military Command and Shenyang Military Command to build a railroad, construct test facilities, and erect measurement stations on top of steep hills. By the end of 1963, the construction of an over-water test facility for shore-to-ship missiles was essentially completed.

In October 1958, the Ministry of Defense decided to change the name of the missile test range to the Navy Test Base to be primarily responsible for the testing of naval weapons such as anti-ship missiles. Zheng Guozhong [6774 0948 0112] was the commander and Wang Dahua [3769 1129 5478] was the political commissar. The base was set up to have a base command, political command, logistics command, scientific research department and over-water test team. In November of the same year, the first naval shore-to-ship missile battalion was established at the base. The first company of the battalion, under the command of company commander Dai Yuqiu [2071 7183 4428], with the assistance of Soviet personnel, studied the technical theory and conducted practical field training and launched a Soviet-made shore-to-ship missile for the first time in June 1959. This enabled the technical staff and missile launch force to acquire some basic skills required for the preparation and implementation of tests.

The testing of guided missile systems requires a well-trained technical test team. In the early 1960s, the Base formulated and implemented a technical training plan to provide training to supervisors, technical staff and operators in test theory and technology. By means of classroom instruction, self-study, school attendance on a short-term basis, and visits to factories and research institutes, special technologies such as missile testing, launching, data analysis, optical measurement, telemetry, synchronized timing, data processing, metrology, target ship remote control, geological survey, hydrology, and meteorology were covered in the training. This program laid down a solid foundation for future official tests.

The most important aspect in missile system testing is the equipment associated with measurement, timing, data processing, targets, navigation, and metrology. When the base was being built, the necessary organizations were set up, equipment purchased and personnel assigned. In 1960, the base combined several existing measurement offices and expanded it into a measurement department in order to speed up the preparation work. After the departure of Russian experts, the base commander completed the installation of a variety of test equipment independent of any assistance from any foreign power. The construction of China's first optical cinetheodolite observation station was soon completed. Immediately afterward, modifications were made to the cinetheodolite, radio measurement device, aerial

camera, data processing and timing equipment. In 1966, the installation and tuning of three cinetheodolites was completed. Along with other equipment, they formed the early stage measurement system at the base. This enabled the Liaoxi Missile Range to begin testing anti-ship missiles.

In the late 1960s, through the joint efforts of relevant development units and the base, an improved cinetheodolite, high-capacity digitized telemetry equipment, infrared laser radar, clock coder, high-accuracy ballistic camera, airborne-fire-control accurate measurement equipment, and similar gear were put into use, enriching and enhancing ballistic measurement systems for missile testing. Simultaneously, to simulate real targets, the base and various development units cooperated to develop stationary, moving, radar, infrared, and television targets and a series of target aircraft and target missiles with different characteristics and applications. Special naval forces and auxiliary ships were created to assume the various tasks involved with this testing, including transmission, projection, image recording, laying, control, and transport of targets. By the end of the 1980s, the base had expanded the various testing facilities of the Liaoxi Missile Range, installed relatively advanced testing equipment, and completed a large number of scientific experiments and design-finalization tests to develop anti-ship missiles.

Section 2. Ship-to-Ship Missiles

Ship-to-ship missiles are installed on board ships to attack enemy surface vessels. They have a longer range than guns and torpedoes and are more accurate and maneuverable. Because a missile is installed on board over a long period of time, heat, humidity and salt air attack its components. Rocking, vibration and noise also affect the launch and flight of the missile. In addition, its exhaust impacts on the equipment and personnel on board. Hence, it is situated in a highly complex and hostile environment which makes the development of the ship-to-ship missile a tall order.

(1) SY-1 (Shangyou-1) Ship-to-Ship Missile

In 1959, China imported a few Po-15 missiles and some production information from the Soviet Union. The missile had a normal aerodynamic layout. It had a liquid fuel rocket engine and a solid booster. It had an independent control system with automatic guidance. The weapon system was comprised of the missile and an onboard fire control system that included a radar control panel and launch device.

In early 1960, following a decision of the Central Military Commission, the National Defense Science Commission and the National Defense Industry Commission went ahead to organize for the duplication of the Po-15. The Fifth Research Academy of the Defense Ministry was put in charge of the technology and had the responsibility of overall design. The Nanchang Aircraft Company of the Third Machine Building Ministry was the missile production unit. Other factories in the Third Machine Building Ministry were responsible for the duplication and production of accessories. In August, the Fifth Research Academy appointed Li Tongli [2621 0681 0500] as Chief Designer. To coordinate the duplication effort, a large number of technical people from the first and second branches of the Fifth Research Academy were sent to factories to learn and digest the information on hand, as well as to resolve design issues encountered. Soon after, the defense industry was reorganized. Progress slowed down. The technical staff at the Fifth Research Academy and the Nanchang Aircraft Company concentrated their resources on getting familiar with the information. By way of reverse engineering, they understood the theory and technical issues associated with the overall design of the missile and its various subassemblies. This created the conditions for us to duplicate the missile and served as a reference for future design of ship-to-ship missiles. In April 1963, the National Defense Science Commission held a special meeting on the Po-15 missile to resolve remaining issues in the duplication effort and to further clarify tasks and responsibilities. The Fifth Research Academy renamed Lu Lin [0712 3829] as Chief Designer.

In order to solve key technical issues in missile development, Chief Engineer Su Min [5685 2404] and Associate Chief Engineer Hua Yizao [5478 1942 5679] of the Nanchang Aircraft Company headed two separate teams to solve all the problems. The fiberglass reinforced plastic nosecone team came up with the warhead forming technique after close to 200 tests. A fiberglass reinforced foam plastic antenna cowling that met specifications was developed in July 1964. Later, a honeycomb sandwiched fiberglass warhead cone that is easier and cheaper to produce and still met the same specifications as the foamed plastic cone was developed on the basis of prior experience in the development of a honeycomb nose for aircraft. In order to solve key technical issues associated with extrusion of the aluminum wing, the Nanchang Aircraft Company put all its design and technical experts together and got help from the Shanghai Casting Institute. After repeated experimentation and verification, problems such as sheet forming, mechanical property, and thermal treatment shaping were solved. It filled a technical void as well. In addition, it also made progress in chemical milling of the rudder and aileron and in argon arc welding of the transformer ring Dewar, oxidant housing and incendiary agent housing. These key technical breakthroughs paved the way for the duplication of missiles. In October 1963, the Po-15 missile was in pilot production at the Nanchang Aircraft Company. In August 1964, the missile passed the static test. In November and December of the same year, under the command of Lu Lin and Vice Commander Bing Ye [0393 6851] of the Naval Test Base, the first land-based launch of a model missile took place at the Liaoxi Missile Range to evaluate the flight of the missile's booster section, the performance of the booster and the effect of the launch on the equipment and personnel onboard. The test was a success.

In 1965, two Russian-built missile boats were used in the Liaoxi Missile Range of the Naval Test Base to test wired remote controlled launch and shipboard launch of model missiles. Five missiles were launched and every one was a success. All missiles left the launching pad smoothly without coming in contact with any structure on board. The personnel, test animals and equipment in the sealed cabin were safe. However, it was found that the original design of the front cover of the launch cylinder on the missile boat was not strong enough. The missile was ignited at the rear. As it passed the front, the cover was distorted and the combustion gas entered the cylinder to tear the cylinder away at its seam. The front cover was torn off and went overboard. After development and test personnel took measures to reinforce the structure, tests were repeated and everything was normal. At the same time, the rocket engine, control instrumentation and final guidance radar were also successfully duplicated by the 111 Plant, 232 Plant, and 781 Plant, respectively.

In May 1965, a shore-to-sea telemetry test was conducted at the Liaoxi Missile Range to evaluate the operating characteristics of various systems of the missile and to determine its accuracy. Three missiles were launched and all were successful. In this test, for the first time, radio telemetry equipment was used at the Liaoxi Missile Range to systematically record relevant data of the missile, providing us with the necessary internal trajectory data for analysis. In order to record the final stage of the missile, movie photographers risked their lives and waited on a small fishing boat in the test range to capture the scene when the missiles approached the targets. In June of the same year, telemetry tests were conducted again over water. Out of three missiles launched, two hit the target. By then, the testing of the Po-15 missile in the development phase was completed.

In these tests, we found many discrepancies between the real object and the data provided by the Russians. In addition, we also uncovered some incompatibility problems between the ship and the missile. The Naval Test Base personnel analyzed these problems, checked with design drawings and took measures to solve them one by one. This ensured the successful completion of the development test.

In November 1966, design finalization tests were conducted on the missile. The National Defense Science Commission, the Navy and all relevant national defense industries put a great deal of emphasis on the design finalization test of the first ship-to-ship missile built in China. The test was conducted under the direction of base chief of staff Wang Jilu [3769 7139 7627]. A total of 12 ships and two aircraft were deployed to launch the missiles, control the target, set up the target and patrol the area. A number of test systems, including optical measurement, telemetry and timing systems, were employed. All participants from various departments were rigorously and fully trained to accurately carry out the technical preparation and launch mission. The test involved fixed targets as well as high speed moving targets. Missiles were launched in single and double shot at different altitudes and ranges. The result was eight hits out of nine launches to successfully wrap up the design finalization test. In August 1967, the design of the first generation duplicated ship-to-ship missile, the Shangyou-1 (SY-1), was approved by the special weapons design finalization committee of the State Council.

(2) SY-1A Ship-to-Ship Missile

The Shangyou-1 used a diaphragm altimeter to control its altitude and had a large error. It used a conical radar scanner which had poor resistance to electronic and wave interference. In October 1973, specifically with reference to these defects, the Nanchang Aircraft Company replaced them with a 2-cm terminal guidance radar and a radio altimeter and successfully completed the flight test of the improved Shangyou-1. In May 1974, the Navy requested approval from the Central Military Commission and the State Planning Commission to start the development of the improved Shangyou-1. In July of the same year, the National Defense Office officially issued the mission to modify the Shangyou-1 and named it the Shangyou-1A. The Nanchang Aircraft Company was responsible for the modification work. Major improvements included the monopulse transistorized small radar developed by the 781 Plant, the radio altimeter developed by the 232 Plant and the simplified engine developed by the 111 Plant. During this period, under the direction of Jiang Longtan [5592 7893 6223], the 232 Plant designed an IC-operational-amplifier-based analog computer control system that met the requirements for the control of missile trajectory at ultralow altitude. Low altitude simulation tests conducted in the third quarter of 1975 showed that the missile was capable of tracking and capturing its target while skimming over the ocean surface.

Between 1977 and 1980, three design finalization tests were performed for the Shangyou-1A. Sometimes it hit the target and sometimes it failed. Besides malfunction of the radar and control on board, the technical staff at the Naval Test Base also found out that the characteristic frequency of the missile played an important role. They believed that the vibration environment of the missile was an important factor contributing to its failure. In order to understand this effect, a comparison test was performed by the Nanchang Aircraft Company using the Shangyou-1 versus the Shangyou-1A. It was discovered that the frequency of Shangyou-1A was lower. In February 1981, Vice Minister He Wenzhi [0149 2429 3112] of the Third Machine Building Ministry chaired a failure analysis and coordination meeting and decided to adopt stringent technical measures to ensure the quality of various components. A large number of tests were performed under the direction of director Peng Lisheng [1756 2980 3932] of the design institute at the Nanchang Aircraft Company. Shock absorbers were put in the radar compartment and measures were taken to reduce the instantaneous impact of the detonator on the radio altimeter. The 781 Plant adopted measures to reduce vibration and selected components that had "seven

specialties" to improve product reliability. In 1982, the fourth design finalization test of the missile was a success. In March 1984, the State Council and the conventional armament design finalization committee of the Central Military Commission approved the design of the Shangyou-1A. The successful development of the Shangyou-1A not only improved the interference resistance of the missile but also made ultralow altitude flight a reality.

As the Shangyou-1A missile was being developed, the Nanchang Aircraft Company continued its effort to study altitude reduction. In November 1979, two reduced altitude tests were conducted for the first time. It was an indication that the mismatch between the radar and the control system was essentially solved. In particular, satisfactory results were obtained from the study of the "multiple pointer" effect of the altimeter and the "multiple path" effect of the radar associated with altitude reduction. In 1983, the Shangyou-1A secondary altitude reduction missile passed an appraisal at the ministry level. This was an indication that the ultralow altitude behavior of the missile had reached an advanced level.

(3) HY-1 (Haiying-1) Ship-to-Ship Missile

In order to strengthen the combat capability of the navy in long range convoy mission, the National Defense Science Commission decided to install the HY-1 shore-to-ship missile on board destroyers as a ship-to-ship missile system. The Third Research Academy of the Seventh Machine Building Ministry was in charge of the overall design and technology, as well as the development of missile fire control panel. The Nanchang Aircraft Company of the Third Machine Building Ministry was responsible for the development and production of the missile. The Seventh Research Academy of the Sixth Machine Building Ministry was responsible for the development of shipboard equipment.

In February 1968, the National Defense Science Commission held a proof of concept meeting for this ship-to-ship missile. The HY-1 is comprised of a missile and a shipboard fire control system. The key to the onboard fire control system was to develop a new control panel and a revolving launch device. The Third Research Academy was responsible for the development of the control panel. It employed a number of new technologies including integrated circuits, redundant operation, automatic switching and self-diagnosis and troubleshooting to improve the performance of the control panel. The triple load revolving launch device designed by the Seventh Research Academy of the Sixth Machine Building Ministry ensured that the revolving area of firing requirement is met.

In order to make the missile adapt to ship movement and meet more stringent temperature and humidity requirements, the Nanchang Aircraft Company made improvements on individual radars, control panels and electrical circuits. Moreover, launch tests were successfully carried out on board older destroyers, as well as on newly developed missile destroyers.

In September 1972, the first missile dynamic aiming test was conducted at the Liaoxi Missile Range and found the initial batch of shipboard equipment to be faulty. The calculated target velocity fluctuated in a random manner. After repeated testing, and by sending simulated radar course to the control panel in stead of using the actual ship movement data, it was discovered that the smoothing function of the computer was not adequate. After taking corrective measures, it was successfully tested again in 1973. The overall accuracy of the weapon system was found to meet our specifications. Associate Director Liang Shoupan of the Third Research Academy and Assistant Chief Wu Baochu [0702 1405 0443] of the Overall Design Department joined the leadership team to solve problems emerged during the test period.

In September 1973, the 051 destroyer missile system underwent its first flight test. Four rounds in single and multiple rounds were fired and all of them hit fixed or moving targets. The test was a success. Vice Chairman Ye Jianying [0673 0494 5391] of the Chinese Communist Party Central Committee was present during the test. He praised the outcome highly. In January 1976, the State Council and the conventional weapon development leadership group of the Central Military Commission approved the design of the HY-1 ship-to-ship missile. Later, at the request of the Navy, the Nanchang Aircraft Company modified the HY-1 to make it compatible with both land and shipboard installation. Furthermore, high and low sea conditions test, biologic test, electromagnetic test and weapon safety test were conducted. In June 1983, the State Council and the conventional product design finalization committee of the Central Military Commission approved the design of the HY-1 ship-to-ship missile and its shipboard weapon system.

In order to enhance the tactical performance of the HY-1, led by Chief Designer Peng Lisheng of the Nanchang Aircraft Company, a frequency agile radar was installed to improve resistance against electronic and wave interference, as well as to enhance its capability to penetrate enemy defense. A radio altimeter was employed to reduce the altitude of the missile and a new automatic pilot was used to enlarge the area of firing. In tests conducted in July to September 1985, four out of four of these modified missiles hit their targets. In February 1987, the modified HY-1 ship-to-ship missile passed its technical appraisal and was named the HY-1A ship-to-ship missile.

Since the 1960s, after more than two decades of hard work, progressing from imitation, independent design, to improvement and enhancement, China has developed a variety of ship-to-ship missiles with different performance characteristics.

Section 3

Shore-to-Ship Missiles

A shore-to-ship missile is a defensive weapon that is launched from the shore against enemy surface vessels. Compared to land-based artillery, it has a longer range and is more accurate and destructive. Its ground equipment may be mobile or fixed. It is usually deployed along the coast or on an island to protect coastal cities or harbors, or to blockade a channel, bay or an area that is more susceptible to enemy attack.

(1) HY-1 Shore-to-Ship Missile

At the end of 1963, as progress was made in the duplication of the SY-1 ship-to-ship missile, the Nanchang Aircraft Company proposed the concept of the HY-1 shore-to-ship missile by modifying the SY-1. After proof of concept and obtaining input from the navy, an official recommendation to design the HY-1 shore-to-ship missile by modifying the SY-1 ship-to-ship missile was presented. In April 1964, in a strategic production meeting, Associate Chief Zhao Erlu [6392 1422 7120] of the National Defense Office delivered a message from Chairman Liu Shaoqi [0491 1421 1142] that we needed to have shore-to-ship missiles as soon as possible in order to deter the enemy at sea. Consequently, the development of this missile was accelerated. At the end of the year, the Nanchang Aircraft Company submitted an overall design scheme to the Third Ministry of Machine Building. During this period, the Fifth Research Academy of the Ministry of Defense also proved a concept of the shore-to-ship missile.

In April 1965, the National Defense Office and the Seventh Ministry of Machine Building held a meeting in which the shore-to-ship missile plan was reviewed by a group chaired by Qian Xuesen [6929 1331 2773]. After comparing the plans proposed by the Nanchang Aircraft Company and the Third Research Academy of the Seventh Ministry of Machine Building, it finally decided on using the SY-1 ship-to-ship missile as the basic model. The propellant container was enlarged, engine operating time was lengthened, and the auto-pilot and terminal guidance radar parameters were adjusted in order to raise its range and improve its performance. The modified model was renamed as the HY-1 (Haiying-1) shore-to-ship missile.

The Nanchang Aircraft Company was responsible for the design and production of the HY-1 shore-to-ship missile. The Third Research Academy was in charge of the overall technology of the weapon system. At the same time, the development and production of the engine, autopilot, terminal guidance radar and combat gear and detonator were assigned to various organizations. After the development work was in full swing, the Nanchang Aircraft Company took advantage of the experience gained in the duplication process to modify and perfect the technical approach under the direction of He Wenzhi [0149 2429 3112] who was in charge of the overall project. He mobilized the entire staff for the development work. Vice Minister Liu Dingzeng [0419 7844 2582] attended numerous briefings and helped solve some of the problems encountered in the development process. In addition, experts such as Associate Professor Zhao Zhenyan [6392 7201 3508] of the Beijing Institute of Aeronautics and Astronautics were also retained as consultants.

The HY-1 shore-to-ship missile had a longer range and it imposed new requirements on testing. Based on the capability of the weapon and testing requirements, the Naval Test Base selected and constructed two new launch sites and created a new test navigation zone. It also rearranged the locations of measurement stations and put in the necessary facilities and roads to ensure that the test could be completed on schedule.

The maximum range of the HY-1 shore-to-ship missile is twice as long as that of the SY-1 ship-to-ship missile. In addition to taking appropriate measures with the engine, the overall thrust had to be raised. The Third Research Academy and the 282 Plant of the Fifth Ministry of Machine Building completed the development of a high-quality engine on schedule. Other development efforts such as the engine at the 111 Plant, the autopilot at the 119 Plant, the terminal guidance radar at the 781 Plant and the ground tracking radar at the 786 Plant were all pressing ahead under full steam. Because of well-coordinated collaboration between development and production departments, very rapid advances were made in the development of the missile and ground equipment. Two telemetry missiles produced by the Nanchang Aircraft Company were shipped to the Liaoxi Missile Range in December 1966. The two launch pads and fuel trucks built at the 437 Plant also arrived at the test site according to schedule. This ensured the flight test of the first missile.

In December 1966, the first flight test of the HY-1 shore-to-ship missile took place at the Liaoxi Missile Range. The range was set at 70 km and the target was fixed. The flight altitude was 300 m. After launch, the attitude and trajectory of the missile were normal and the heading at the end of the automatic control segment and the longitudinal scatter were also within specification. However, after the missile finished its maximum range, the terminal radar did not capture the target. After that, three more flight tests were conducted. Nevertheless, the same problem persisted. In July 1967, the National Defense Science Commission and the National Defense Office held a meeting chaired by Qian Xuesen, Zhao Lianqing [6392 3425 7230] and Ma Xuelin [7456 1331 2651] to discuss this problem. It was concluded that the vibration of the missile caused the terminal radar to function intermittently. Associate Director Liang Shoupan of the Third Research Academy went to the test site to conduct an analysis. He recommended that the front of the launch guide rail be cut short by 1.2 m and the bottom plate of the exhaust trough be deflected downward so that it was almost parallel to the jet from the booster to minimize vibration. At the same

time, at the Nanchang Aircraft Company an experimental study was done under the direction of Cheng Shaozhong [4453 4801 1813]. It was found that the projectile body was not rigid enough and the gap between the radar and projectile body was too small. After taking measures to reduce radar vibration and to thicken the skin of the projectile body to raise its rigidity the problem was solved. In October 1970, the design-finalization flight test was a success. The HY-1 shore-to-ship missile went through 25 flight tests in the development phase. Its design was approved by the Naval Weapon Design Finalization Committee in August 1974.

(2) HY-2 Shore-to-Ship Missile

In order to strengthen our defense against enemy from the sea as instructed by the Central Military Commission, the navy asked for the development of a long-range shore-to-ship missile. The Third Research Academy conducted some work to demonstrate several concepts. Associate Director Zhao Erlu and Bureau Chief Liu Zhengdong [0491 2973 2767] of the National Defense Office attended the discussion meeting held by the Third Research Academy and listened to the inputs from various sources. After an in-depth analysis, a scheme based on the HY-1 missile with an increased range was presented in June 1965. In August, the Central Special Committee included this model into the national plan and named it the HY-2 missile.

Under the leadership of Director Lin Yi [2651 3015], the newly-founded Third Research Academy was involved in construction, design and development at the same time. The proof of overall scheme and design work was done under the direction of Vice Chief Cao Bozhen [2580 2672 2823] of the total assembly design department and Chief Li Tongli [2621 0681 0500] of the total assembly office. The missile had to have a longer range and the same accuracy. This became the key technical issue in the development of the HY-2. In order to accomplish this objective, the Third Research Academy adopted a series of technical measures to lengthen the operating time of the liquid fuel rocket engine, improve the performance of the second stage rocket, solve the overheating problem in the cooling channel, use a force-bearing oxidant tank manufactured by chemical milling, and resolve the contradiction between force transfer and projectile rigidity due to increased volume, weight and length of the propellant tank. It developed a new navigation gyroscope that is more accurate, enlarged the search sector angle and auto-guidance range of the terminal guidance radar, redesigned the trajectory, reanalyzed the circuitry and altered parameters associated with the control and radar. A new command panel, coastal tracking radar launch pad and transport and fueling vehicle were also developed and constructed.

The pilot production of the HY-2 was also a key issue. The pilot assembly plant at the Third Research Academy was a small facility for machining non-standard equipment. The plant was small and inadequately equipped and staffed for this job. Moreover, there was a big gap in the level of technique available. In order to meet the deadline imposed by the Seventh Ministry of Machine Building to complete the pilot production using existing resources within one year, the Third Research Academy decided to send all technical people who were involved in the duplication effort in the past at the design department to the assembly plant to handle technical problems associated with the model construction and pilot production. The plant was responsible for solving equipment and technique related problems. With the support of the Nanchang Aircraft Company and the 211 Plant, the first static test missile was produced in August 1966.

Progress was also made in the development of onboard ancillary equipment and ground facility. Under the leadership of Chief Designer Kang Liansen [1660 5114 2773] and Assistant Chief Designer Wang Shusheng [3769 2885 5116], the 111 Plant and the 31 Institute of the Third Research Academy modified the engine. After more than 20 individual tests and 14 hot-firing tests, they developed an engine that was qualified for prolonged operation. In addition, the autopilot jointly developed by the 119 Plant and the 3rd Institute of the Third Research Academy and the terminal radar developed by the 781st Plant of the Fourth Ministry of Machine Building were delivered on time to be installed in the missile. Under the direction of Chief Engineer Zhang Xixiong [1728 6932 3574], a ground tracking radar that met both searching and tracking requirements was developed at the 781 Plant of the Fourth Ministry of Machine Building by modifying the Model 864 coast artillery radar. Its design was furthered modified and simplified by the Shanghai 101 Plant and other production plants on the third line and its components were transistorized to improve its accuracy, interference resistance and reliability. On the basis of a computer developed at the 706 Institute, together with the optical coding dial developed by the 23rd Institute of the Second Research Academy and the A/D (analog-to-digital) and D/A (digital-to-analog) converter developed by the Metrology Station of the Second Research Academy and the 704th Institute of the First Research Academy, the Third Institute of the Third Research Academy developed a digital command panel. During road test, experts such as Zhang Zichang [1728 2737 2490] of the 706 Institute and Assistant Chief Wu Baochu [0702 1405 0443] were inside the test vehicle to obtain first-hand information on the test data. The Third Research Academy was in charge of the launcher and the transport and fueling vehicles. It was designed with the assistance from the Beijing Industrial College and Naval Test Base and manufactured at the Hudong Shipyard and the 349 Plant. The electric power generator vehicle was developed by the Zhengzhou Electric Appliance Factory and the Lanzhou Consolidated Electric Machinery Factory. The overall test vehicle and the pre-launch inspection vehicle were designed by the Third Ministry of Machine Building and manufactured at the general assembly plant of the Third Research Academy. Thus, the ground system that was comprised of several dozen vehicles was

also ready on schedule. In November 1966, the entire ground system was tested as a whole.

From September 1966 to March 1967, the missile underwent static tests, vibration tests and engine test firings on the ground as a complete missile. The results indicated that the technical measures taken to increase the range of the missile and the design of the projectile body were stable and reliable. The precision of the fire control system affects the accuracy of the missile and the magnitude of deviation at the end of the flight in automatic control. It had to be checked out prior to any flight test. The technical staff of the Liaoxi Missile Range and the Third Research Academy jointly determined specific schemes including test routes, number of flights, and data acquisition and processing. After dozens of tests, the fire control system was found to meet design specifications. In addition, problems such as the computer smoothing system were resolved as well.

In September 1967, the first batch of telemetry missiles arrived at the Liaoxi Missile Range. It so happened that the HY-1 missile was also being tested at the test site. Problems such as radar failure and "short projectile" (missile falling into the water before completing its pre-determined flight) were discovered with the HY-1. In view of these problems, Liang Shoupan and Wu Baochu decided to adjust the return angle of the terminal guidance radar of the HY-2 to ensure the successful test launch of the first missile. On this basis, an automatic return mechanism has been added to the radar antenna of the HY-2. Afterward, three more missiles were successfully launched. The development flight test was competed with a 4-out-of-4 record.

In August 1969, the design finalization flight test for the HY-2 was done at the Liaoxi Missile Range and the outcome was 4 out of 5. In March 1970, the naval shore-to-ship missile unit simultaneously launched several missiles in a design finalization test. The sea was very rough on that day and the target vessel was light, rolling so violently that onboard personnel could not be evacuated. The commander was burning with impatience. However, in order to carry out the test mission successfully they insisted on proceeding and ignored their personal safety. Two missiles hit the target. By then, the design finalization test of the HY-2 was completed with an excellent record of 6 out of 7.

From the onset of development in 1985 to the completion of the design finalization test in 1970, it took 5 years to develop the HY-2. Thirteen missiles were used in ground and flight tests. A total of 11 missiles were launched and 10 hit their targets. This was a good beginning for the development of anti-ship missiles in China. Furthermore, we gained the valuable experience that a missile design must be advanced, stable and reliable and then needs to be fully validated and tested. This effort laid a solid foundation for the future.

(3) HY-2A Shore-to-Ship Missile

In order to overcome the deficiency that the interference resistance of the terminal guidance radar of the HY-2 is relatively poor, and to improve its penetration power, it was decided to change its radar-guided head to an infrared-guided head and named it the HY-2A, or infrared missile.

In the discussion stage of anti-ship missile development in the 1960s, Qian Xuesen proposed to work on infrared guidance because the terminal guidance radar is more susceptible to interference. To employ infrared guidance in an anti-ship missile, problems such as high variability of the infrared characteristics of the target, difficulties involved in the automatic search, capture and tracking over a long range and complex background interference of the ocean must be resolved. The key is the infrared detector. An in-depth feasibility study was done under the leadership of Director Zhong Renhua [6988 0117 5478] of the Infrared Laser Institute of the Third Research Academy. After a large number of tests, indium antimonide was chosen as the infrared detector. Researchers conducted a great deal of preliminary experiments on the infrared characteristics of the target and background and the infrared device, validated the design of the infrared guidance system and successfully developed the indium antimonide detector and the magnesium fluoride glass cover. Following six tests over the ocean, the development of the prototype infrared guidance head was completed. At the same time, the overall design of the HY-2A was validated under the leadership of Chief Missile Designer Xuan Ping [1357 1627]. It was obvious that the key issues were to resolve the profile of the missile head and the installation of the IR head. As a result of wind tunnel tests, a small spherical profile was chosen out of the five tested. The missile head was reinforced. The indium antimonide detector was cooled by purified air instead of liquid nitrogen. A zero adjustment mechanism was designed to control the relative position between the optical axis and the missile axis. These measures solved the key problems encountered in the development phase.

In 1974, a ground simulation test of the infrared head and the entire missile system was carried out at the Infrared Institute of the Third Research Academy to verify the overall performance of the missile. Technical problems such as instability in search and loss of target were resolved. Nevertheless, in two development flights in 1975 and 1977, the problem of intermittent target capture and loss of target resurfaced. Another technical team was organized. The control parameters were redefined and the connection with individual pieces of ground equipment was retested to solve this problem. At the same time, the Naval Test Base was also actively preparing for testing the missile with an IR guidance head. Technical staff of the target group, working in collaboration with designers of the Third Research Academy, developed a compact infrared target which simulated the heat source of a medium to large vessel. It

could be installed on a fixed target vessel or a remote control vessel to meet the needs of IR missile testing.

In September 1980, the HY-2A underwent its design finalization flight tests. The first missile launched missed the target laterally. After a check by the development and testing staff, it was found that there was an error in the production drawing of the circuit plugged into the left of the launcher, causing the onboard gyroscope to unlock before the missile was launched. After correcting this error, the flight test resumed. It was successfully completed with a 5-out-of-6 record. In 1982, the State Council and the Conventional Weapon and Equipment Design finalization Committee of the Central Military Commission approved the design of the HY-2A missile.

In order to enhance the tactical performance of the missile, the technical staff of the Third Research Academy improved the infrared guidance head and the altimeter. They developed a new infrared guidance head, improved the modulation algorithm and expanded the effective attack target range. They eliminated the diaphragm micro barometer and installed a radio altimeter instead. They lowered the altitude of the missile to further enhance its penetration power. In 1984, in its validation test of the modified missile, the outcome was 3 out of 3 and all major strategic and tactical specifications were met. It was named the HY-2A-II.

(4) HY-2B Shore-to-Ship Missile

In order to enhance the penetration power of the shore-to-ship missile, our development people continued to make improvements on the HY-2. A monopulse radar guidance head was installed to improve its interference resistance. A new altimeter was used to reduce the altitude of the missile to an ultralow altitude. The improved missile was named the HY-2B, or the reduced altitude missile. In 1975, under the direction of Chief Designer Cao Bozhen [2580 2672 2823] and Designer Yang Xinsheng [2799 2450 3932] of the Total Assembly Design Department of the Third Research Academy, the total assembly scheme was validated and designed. In order to ensure the accuracy of guidance, they chose the two monopulse terminal guidance radars developed by the 239 Plant and the Third Line Plant of the Third Research Academy to improve the performance of the guidance device. They selected the radio altimeter developed by the 558 Plant to improve the altitude measurement device and to lower the cruising altitude. They adjusted relevant control parameters to resolve the safety problem associated with the cruising of the missile after it completed its descent and the "short shot" problem in the self-guiding segment. During a test flight in 1977 it was found that the altimeter manufactured by the 558 Plant and selected by the 159 Plant was on the high side. After adjusting the control parameters and through tests over a wave-making basin and over the ocean, our development personnel found the cause and took corrective action. In 1979, the HY-2B successfully completed its development flight test. In 1982, it passed its modeling fixing test with a 5-out-of-6 record. In January 1984, the design was approved by the State Council and the Conventional Weapon and Equipment Design Finalization Committee of the Central Military Commission. The radar guidance head has always been the key to the performance of the HY-2 missile. To this end, the third line base of the Third Research Academy developed a variable frequency head and was successfully tested in a missile in 1989. It was named the HY-2B-II.

The development of the HY-2 shore-to-ship missile began in 1965 and was successfully completed in 1984. Four models were produced, including an infrared version and a reduced altitude version, to form a complete series. Our practice proved that it is a successful experience to continuously improve and develop new models on the basis of a successful base model.

Section 4. Air-to-Ship Missile

An air-to-ship missile is launched from an aircraft against a surface vessel. An air-to-ship missile system is comprised of an aircraft, missile, airborne fire control system and ground testing and loading equipment. It has a long range, covers a large combat area and is highly maneuverable. It is a major weapon for naval air power.

(1) Concept Validation of Air-to-Ship Missile System

In the mid 1960s, the Navy and the Air Force both proposed to equip H-5 and H-6 bombers with missiles. In 1966, the Third Research Academy of the Seventh Ministry of Machine Building established an air-to-ship missile research laboratory at the Third Design Department and appointed Yao Shaofu [1202 4801 4395] and Yang Jingqing [2799 4842 0615] as technical leaders in charge of concept validation. The National Defense Office and the National Defense Science Commission reviewed the design in May of the next year and decided to modify the HY-2 to develop an air-to-ship missile. To this end, the Third Research Academy organized wind tunnel model missile launch tests to analyze the performance of the rocket engine in a high-altitude, low-temperature environment. An improvement plan was presented. However, due to the Cultural Revolution, the development was stopped. In September 1975, the Central Military Commission approved the resumption of air-to-ship missile development. On the basis of the original air-to-ship missile plan approved by the National Defense Office, following the principle to choose off-the-shelf items to the extent possible in order to arm units in the field with hardware as soon as possible, the Third Research Academy restarted the air-to-ship missile development.

(2) Development of YJ-6 Air-to-Ship Missile

In 1975, under the direction of Lu Shiguang [6424 0670 0342] and Yang Jingqing, further validation of the air-to-ship missile was completed. It was also coordinated with the aircraft fire control system. It was made

clear that air-to-ship missile must be developed based on existing technical accomplishments. Compatibility between different models and selection of general purpose ground equipment must also be taken into consideration. Materials and components chosen must be domestic and standardized. Because these guidelines were strictly obeyed, the design was continuously modified, and major problems were tested and resolved in time, these steps played an important role in perfecting the weapon system and shortening the development cycle.

Based on the tactical requirements of the air-to-ship missile, the design incorporated an active monopulse terminal guidance radar, that is capable of resisting interference from wave, clutter, asynchronization and drag distance, and a radio altimeter in order to improve its low altitude penetration, interference resistance and survival probability. A digital command mechanism was used so that the missile could issue various commands to switch its working condition accurately and reliably. A Doppler radar was added to overcome the deleterious effect of wind velocity variation at different altitude on the terminal point at the end of the self-guided segment. Trajectory heading control and longitudinal range control were implemented to enlarge the launching air space. An oxidant emergency discharge system and a gas filling heating system were added to satisfy special requirements and safety concerns for air-to-ship missiles.

In April 1977, the Third Ministry of Machine Building, the Fourth Ministry of Machine Building, the Fifth Ministry of Machine Building, the Eighth Machine Building Bureau and the Navy jointly reviewed the plan for the air-to-ship missile system and decided to modify the H-6 bomber to carry the air-to-ship missile. In addition, the Third Research Academy was put in charge of the missile system. The carrier bomber was to be modified at the Xian Aircraft Company. The aircraft was named the H-6D and the missile YJ-6. In October, the State Council and the Central Military Commission approved the "Development Plan of H-6D Bomber Carrying YJ-6 Missiles." All units immediately proceeded with the development. After repeated validation and experimentation, Chief Designer of the YJ-6 was Lu Shiguang and Assistant Designers Yao Shaofu, Yuan Jianying [5913 6015 5391] and Li Shipei [2621 0013 1014] believed that the key issue to address and resolve in the development of an air-to-ship missile is that the quality of all components must be very high because the missile will have to endure a variety of hostile environmental factors such as low temperature, low pressure, vibration and aerodynamic interference from the airplane and the missile itself.

Under the direction of Fan Yongqing [5200 3052 337], the 239 Plant began to develop a monopulse terminal guidance radar in 1977. After 2 years of effort, a prototype was constructed and put on test. In 1981, a new terminal guidance radar with a novel anti-jamming circuit was developed. Its anti-jamming behavior was tested in early 1982 and found to be satisfactory. It became a new generation of guidance radar at the time.

The 8357th Research Institute was responsible for developing the onboard digital command mechanism by placing small digital logic components in digital mechanisms. Through a large number of tests and numerous design modifications, an accurate, stable and reliable command mechanism was finally developed. It is capable of executing programmed commands and range control command based on logic determination. It is a good beginning for the digitization of onboard devices.

The Doppler radar in the missile was a joint effort between the 782 Plant of the Fourth Ministry of Machine Building and the missile design unit. It was developed by modifying an airborne Doppler radar. Technical breakthroughs were made to meet design specifications.

(3) Modification of H-6D Bomber

The H-6D bomber is the carrier of the YJ-6 missile. It is equipped with an onboard missile fire control system, an automatic navigation bombing system, a missile heating system and an aerial radar system. The missile fire control system is the key in the development of the YJ-6 missile system. It employs a system that combines an airborne radar with a firing command panel. It can perform track-while-scan and is highly accurate and has a long useful range. The entire fire control system is installed on the H-6D bomber to search and track targets, determine target movement parameters, calculate missile firing parameters, perform automatic prelaunch inspection and control missile launch. In order to accelerate the pace of development, despite the hardship caused by the Tangshan earthquake, the 8357th Research Institute worked hard day and night in earthquake damaged buildings to conduct research and experiments under the direction of Director Li Shipei [2621 0013 1014] and Chief Engineer Dai Weiling [2071 1218 1545]. Very quickly, they resolved key issues such as radar video signal control and post-quantization digital data processing. In November 1979, performance verification was tested in air and the results were found to meet design specifications.

In July 1983, in the development of the airborne fire control system, Lu Shiguang and Yang Jingqing proposed to incorporate an inertial guidance device. It was approved by the National Defense Science Commission. This measure improves the accuracy and reliability of the fire control system to ensure the probability of a hit.

(4) Testing of the YJ-6 Missile

A series of flight tests was arranged in the development of the YJ-6 missile to check out the design and verify technical coordination in order to discover and solve problems. These tests were done over land and sea, respectively.

The test flight of YJ-6 is much more complicated than that of a shore-to-ship missile. First, it requires a large air space, usually over two provinces and three cities, covering two major military zones. It involves ships, aircraft, ground support, and technical personnel for measurement, control and protection. It is difficult to organize such a team. Second, a special target suitable for the onboard radar to detect is required when a missile is to be launched from an airplane at a high altitude from a distance to ensure the capture of the target. Third, it requires simultaneous tracking of the airplane, missile and target. It involves a large number of measurement and control stations scattered over a large area. The measurement work is highly complex. Fourth, during the test, development, design and test personnel cannot travel with the airplane to observe the operation of onboard equipment. These unique situations demand a rigorous organization and close coordination.

In 1978, the first test flight of YJ-6 took place at Yanliang Field in Shanxi. When the H-6D bomber took off with the missile for the first time, the aircraft vibrated violently. An analysis showed that it was caused by the bomb bay door that had been enlarged to accommodate the missile. As the aircraft picked up speed, the rigidity of the fuselage decreased. After making modifications to the doors, the aircraft behaved normally. Simulation of fuel dumping in mid-air was also successfully completed. The measurement of telemetric direction pattern in test flight is highly complex and difficult. Our flight crew had never done it before. To this end, the Third Division of Naval Aviation chose Assistant Chief of Staff Gao Fuchang [7559 4395 2490] as the navigator and Assistant Battalion Commander Ma Baorui [7456 1405 3843] as the pilot. In order to acquire data reliably, four sets of equipment were used to record the data. Due to sufficient preparation and a well designed plan, the mission was accomplished after two flights. In the same year, an exploratory launch test of the YJ-6 was conducted at the air-to-air missile test base to investigate issues such as how missiles are to be carried on the aircraft, what is the glide path of the missile, and what kind of mutual interference there is between the missile and aircraft. Three automatic control missiles were launched in this test. However, the first two fell to the ground before assuming a horizontal flight path. Technical personnel analyzed various problems and discovered that the polarity of the pitch gyroscope was incorrectly connected. After eliminating the problem, the third missile launched glided normally, the engine was ignited according to program and the missile descended to 100 m and flew horizontally. The test was a success.

In 1981, the accuracy of the fire control system was tested. First, an avionics oscilloscope was used as a data recording device to conduct some simple accuracy tests. It was followed by conducting an aiming accuracy test at the Liaoxi Missile Test Range. This test requires an aerial measurement system to obtain data such as the attitude of the aircraft and the ground speed drift angle. Technical personnel at the Liaoxi Missile Test Range, including Zhao Peizhi [6392 1014 1807], worked on this project for years with the cooperation of the 630th Institute and 141st Plant of the Ministry of Aerospace Industry and finally completed its development.

In the accuracy test, the target ship, cruise area and measurement facilities were all deployed over the Liaoxi Missile Test Range. The aircraft took off from Shanhaiguan Air Base. The first step was to calibrate the airborne Doppler radar. After collecting a large amount of data during several dozen flights, the aiming accuracy of the airborne fire control system was found to essentially meet design specifications. In order to further improve its accuracy and to overcome the shared-frequency asynchronous interference problem of the Doppler radar, aerial inertial guidance and ground speed drift were introduced to the missile fire control system. The accuracy of this inertial guidance control system was tested and the result was apparent. This work laid a solid foundation for the design finalization test for the weapon system.

In July 1981, the National Defense Science Commission and the National Defense Office conducted a thorough experimental study on air-to-ship missile in order to determine task assignment and organization principle. A variety of test organizations were established. Tian Zuocheng [3944 0155 2052], Group Leader of the on-site test group and Commander of the Naval Test Base, was responsible for organizing the test work.

Developmental test flight of the YJ-6 over water began in late 1981. In order to verify the performance of missile equipment on board of an aircraft in the air, a simulation test was done in the early stage. This is an economic way to test the system. With the exception of not launching the missile after pushing the firing button, every step is carried out as if it is a real launch. After the aircraft returns to base, the control panel prints out various firing parameters to reveal all the relevant data. Through this simulated missile carrying test, major technical issues, such as aircraft vibration, were discovered and resolved. It also shortened the test cycle and is an innovation in the development of the YJ-6 missile.

Developmental test flights of the entire YJ-6 missile system over water began in early 1982. The primary objective was to evaluate the capability of the fire control system to track moving targets and the performance of the missile at various ranges when the aircraft is flying at an altitude of between 1,000 to 9,000 meters. Those responsible for launching the missile and operating the fire control system were Ma Baorui, Vice Battalion Commander, Third Division of Naval Aviation, Di Xijie [5049 6007 2638], navigator Zhang Junde [1728 0193 1795], and the entire crew of H-6D bomber number 80334. Despite having participated in numerous simulated carry and launch tests, they still underwent a series of training exercises to ensure the success of the mission. The 7th Division of Naval Aviation and Shanhaiguan air base provided accurate direction and ground protection to the H-6D bomber. The Liaoxi Missile Test Range

developed a special double-layer reflector target that reflects radar signals evenly and arranged test flights to check a variety of measurement equipment, calibrate the radar, conduct dynamic accuracy tests, inspect the inertial guidance system and simulate the trajectory. In every test, all participants arrived at Shanhaiguan air base ahead of time to provide sufficient preparation for the missile and onboard equipment. Comrades from superior organizations such as the National Defense Science Commission, National Defense Office, Navy, Air Force, and the 3rd, 4th, 5th, 6th and 7th Ministries of Machine Building were also present to provide guidance to the test.

On 19 June 1982, the first missile was launched from an H-6D bomber at low altitude and the missile cruised normally and hit its target. Afterward, three additional missiles were launched from the H-6D bomber at different altitudes and they were all direct hits as well. This test was done to evaluate the performance of the missile at maximum and minimum altitude, maximum and minimum range with respect to either a fixed or moving target ship in both winter and summer conditions. The developmental test over water was a success.

In 1984, the YJ-6 missile underwent its design finalization test. Personnel from various organizations performed rigorously inspected and tested the missile and onboard equipment based on the test protocol to make sure the technical preparation is done well. Seven missiles were launched in this test at different altitudes from as high as 9,000 meters to determine the behavior of the missile at different cruising altitudes and extreme self-guidance range, as well as its resistance against shared-frequency asynchronous interference. Both fixed and moving target ships were used. The result was 4 out of 4 to conclude the design finalization test. In 1986, YJ-6 passed the national design certification.

Section 5. Multi-Mission Anti-Ship Missile

Having successfully duplicated, improved and independently developed its own anti-ship missiles, China had the ability and resources to develop new anti-ship missiles. Because anti-ship missiles with liquid fuel rocket engines are difficult to maintain and use, the Navy requested the development of a low maintenance, compact, multi-mission, solid fuel anti-ship missile to enhance our combat capability. To this end, China began its development of a multi-mission anti-ship missile beginning in the late 1960s.

(1) Exploring the Way for the Development of a Small Multi-Mission Anti-Ship Missile

In 1970, the Naval Aviation Command asked the Third Research Academy to develop a small supersonic missile for the Qiang-5 torpedo bomber. Yao Shaofu et al. at the Total Assembly Department of the Third Research Academy initiated a preliminary feasibility study for the development of a small anti-ship missile. Director Yu Xiaohong of the Third Research Academy decided to organize all the resources to strengthen the development of a solid rocket anti-ship missile. After repeated validation, balancing out the requirements of the three major specifications, i.e., speed, range, and warhead size, and taking the needs of the troop and technical feasibility into consideration, it was determined that a multi-mission approach should be adopted. In terms of the development sequence, ship-to-ship comes first and air-to-ship follows, short range first and long range later. In 1973, the Third Research Academy submitted a small anti-ship missile development plan. In November 1975, the Navy held a review meeting on the overall design of a small anti-ship missile and the technical requirements of various sub-systems. In September 1977, the State Council and the Central Military Commission officially approved the small missile development plan and named it the YJ-8 missile.

(2) Preliminary Research on the YJ-8 Missile

The YJ-8 missile is supposed to fly at an ultralow altitude and at a high subsonic speed. Moreover, it must have a certain range. It is necessary to develop a low-thrust, long-operating-time cruising engine. Back then, although China had some experience in the development of solid rocket engines, there was nothing of this caliber. There was nothing like this in the open literature abroad. A technical breakthrough in the operating time of the solid rocket engine was a key issue in the development of the YJ-8. In 1970, a group led by Ding Zhenzong [0002 2182 1350], Zheng Bingsen [6774 3521 2773] and Chang Jingji [1603 2417 1015] was formed to develop the solid rocket engine at the Third Research Academy. With a weak technical foundation and lack of information, they picked up knowledge as they went on. They found help from a variety of places, including the 508 Institute, Second Department and the Fourth Department of the 7th Ministry of Machine Building, the 845 Plant of the 5th Ministry of Machine Building, the Northwest Rubber Research Institute and the Beijing Steel and Iron Research Institute. After numerous experiments, technical hurdles went down one by one. In October 1973, the first long-operating-time solid rocket engine was developed and underwent ground test. They summarized their experience and continued to make improvements by adjusting parameters. After 5 years of hard work, a breakthrough in long-nozzle engine technology was made.

In the second half of 1977, the Third Research Academy formed a solid rocket engine laboratory. The development team was fortified and a test platform was constructed. After repeated tests, key technical problems such as the melting of the long nozzle and excessive ignition delay were also resolved. Propellant packaging technique was improved by tightening the procedure and strengthening the quality control in order to stabilize the pressure and thrust of the rocket engine. The development of this low-thrust, long-operating-time solid rocket engine was smoothly completed.

The advanced research on the high speed composite propellant booster was done by the 31st Institute of the Third Research Academy. A team led by Qiu Shanchang [6726 0810 2490] was in charge of concept validation. A high density charge design by wall casting with a star-shaped hole in the center was adopted. Nevertheless, during the prototype development stage, explosions that occurred in the production of the high-speed thiokol propellant forced them to abandon the approach. They then decided to use the high-speed butyl hydroxy composite propellant that was still under development in the laboratory. With the cooperation of the technical staff and workers at the 7013 Plant and the Changchun Institute of Applied Chemistry, the new propellant was successfully developed and loaded in the prototype engine. In February 1978, the internal ballistic was found to be excellent in a ground test. This effort provided considerable experience in the use of the butyl hydroxyl propellant for tactical rocket engines.

The YJ-8 missile needs a small, lightweight, compact autopilot. In 1977, Assistant Manger Yi Sheng [2496 3932] of the 558 Plant of the Third Research Academy organized a group of young technical professionals such as Song Youshan [1345 2589 1472] to address this issue. After an in-depth survey and validation, they decided to abandon the conventional control panel and to develop a small dedicated multi-functional analog computer to replace a part of the circuits. In the control module, active electronic differentiators, integrators, integrated circuits and amplifiers were used to replace certain electromechanical devices in order to improve performance and reduce volume and weight. This simplified the "hardware" of the control panel to make its downsizing a reality.

In order to fly at an ultralow altitude, it is necessary to develop a highly accurate, sensitive radio altimeter that is also not susceptible to wave interference. In the early 1970s, the 558 Plant and 239 Plant of the Third Research Academy simultaneously received the assignment to develop such a radio altimeter. A solid state FMCW radio altimeter and a solid state constant-beat servo slope radio altimeter were developed by respective parties. They were both capable of controlling the missile skimming over water surface.

In order to reduce the volume and weight of the control panel, and to overcome the deficiencies of the electric rudder and hydraulic (or pneumatic) servo motor, the 558 Plant successfully developed an indirect electric servo-mechanism—the magnetic powder clutch rudder. This rudder structure is simple. It not only serves as a rudder but also is a part of the missile. It plays an important role in the downsizing and weight reduction of the control panel.

Developing a highly effective, small terminal guidance radar is a major technical issue in order to meet tactical requirements of the missile, as well as to reduce its volume and weight. Associate Director Tang Guofu [0781 0948 1381] and his technical staff at the 239th Institute of Radar Research broke away from the conventional structure and adopted an integrated design to make the radome and the radar an integral section of the missile body. The space available is fully utilized. All the radar components are rigidly fastened to the missile without the use of any shock-proof device. Its weight is approximately one-half that of a conventional radar. Furthermore, it solved the electrical inductance problem associated with the fact that the entire terminal guidance radar is installed inside the missile. In the area of interference resistance, technical breakthroughs were also made. Effective ways were found to improve resistance against clutter, range drag, shared-frequency asynchronous and other active interference and passive wave interference. After years of hard work and repeated testing, a fully transistorized, structurally integrated, monopulse, interference-resistant, single plane active terminal guidance radar was successfully developed. Its major tactical specifications are at advanced 1970 world-class level.

The YJ-8 employs a semi-armor-piercing warhead and a novel electrical delay fuse. This warhead penetrates a ship with its kinetic energy and then explodes. Its overpressure effect is much larger than that of an external explosion. This enhances the power of a small missile despite a substantial reduction in weight and volume as a result of downsizing the missile. In September 1978, the Design Department of the Third Research Academy asked the 5013 Plant to develop this novel warhead. The Third Line Base Factory of the Third Research Academy was asked to develop the electromechanical delay fuse. In order to perfect the warhead design, the 5013 Plant conducted charge loading experiment, simulated warhead armor piercing experiment, environmental test, warhead static ground explosion test, and warhead-fuse combination static ground explosion test. The results obtained were found to meet our tactical requirements. In order to meet the technical requirements that two different points inside the warhead must be ignited within a few microseconds, the Third Line Base Factory of the Third Research Academy successfully developed a delay trigger fuse that has three independent levels of safety under the direction of Chief Designer Li Yinshan [2621 0603 1472]. The power of the warhead and the delay time of the fuse were found to meet our tactical requirements after a dynamic armor piercing test of the warhead/fuse assembly.

(3) Development of the YJ-8 Missile

After the State Council and the Central Military Commission approved the YJ-8, the Third Research Academy began full-scale development work. In August 1978, the Navy, the 3rd Ministry of Machine Building and the 8th Bureau of Machine Building jointly reviewed the scheme for the weapon system involving using Q-5 torpedo bombers to carry YJ-8 missiles and the specific plan for the missile. Technical coordination between the missile and the bomber was also made. Furthermore, the 239 Plant of the Third Research Academy was assigned

as the main assembly plant for the missile. Various plants and institutes were given the assignments for the assembly of different subassemblies.

The design and validation of the YJ-8 was done under the direction of Wang Zuquan [3769 4371 0356], Assistant Chief of the Design Department of the Third Research Academy. In order to achieve high subsonic, ultralow altitude flight over water, a two-stage solid rocket engine with an "automatic control" and "self-guiding" guidance system was chosen. A small autopilot using a dedicated analog computer as its core component, a high-accuracy radio altimeter, a digital timer and an interference resistant monopulse terminal guidance radar were also employed. The warhead is of the semi-armor-piercing type with an electromechanical delay fuse. The launching device is a storage, transport, and launch container.

In 1978, the Third Research Academy reinstated the model design system. Bao Keming [7637 0344 494], Lu Shiguang and Yao Shaofu acted as chief designers of YJ-8 at different times to further strengthen the technical leadership of its development effort.

Since it undertook the YJ-8 project, the 239 Plant as a whole worked very hard to modify existing facilities to build a prototype production and assembly line. This effort not only saved a great deal of money but also took full advantage of the potential of an existing plant to assemble prototype missiles. Consequently, it accelerated the progress of YJ-8. After a 2-year effort, it overcame technical difficulties associated with the construction of the wing, casting of the projectile body and testing of the full assembly. With excellent coordination among the primary and secondary development units, the first YJ-8 was completed in 1978.

Development stage flight tests of the missile were all conducted from the coast. Upon the successful launch of two missiles in 1978, it was decided to begin directly testing automatic control missiles. From November 1979 to November 1980, seven automatic control missiles were launched. With the exception of one failure due to booster ignition circuit malfunction, the others were a success. These tests not only validated the design concept but also verified the accuracy of the automatic control of the missile. In 1981, test flights took place for development purposes to evaluate the behavior of the entire weapon system, the safety and reliability of its launch, the coordination of various sub-systems, its guidance program, trajectory, and accuracy. In this test, five missiles were launched. Although the test was a success, it exposed a number of technical and quality issues such as inadequate missile rigidity, poor reliability of the booster fuse, loosening of the separation plug and the burning through of the booster. Superiors from the Ministry of Aerospace Industry, including Zheng Tianxiang [6774 1131 4382] and Lin Shuang [2651 3642], instructed the Third Research Academy to conduct a thorough search to pinpoint such quality and management problems by summarizing the experience of the YJ-8 test flight. To this end, the Third Research Academy underwent a quality reorganization. A comprehensive technical responsibility system was established and quality control regulations were revised. Problems surfaced in the development of the missile were solved one by one. A series of stringent and effective quality control tests, centered around the final assembly plant, was implemented to ensure the proper preparation for the design finalization test.

After successful launches of model and self-guidance YJ-8 missiles, the design of its carrier Q-5 torpedo bomber was not ready. In order not to adversely affect the progress of the YJ-8 weapon system, the 8th Ministry of Machine Building and the Navy agreed to test the YJ-8 on the Model 24 fast missile boats. In August 1981, the Office of Chief of Staff and the National Defense Office jointly approved the fast missile boats as the carriers for the YJ-8 and began the validation of the weapon system. The 8th Ministry of Machine Building and the Navy reviewed plans for the missile system and the modification of the boat. The 701st Institute of the 7th Ministry of Machine Building was in charge of the modification of the boats and related technical issues. In October 1982, the National Defense Science, Technology & Industry Commission officially issued the assignment to retrofit the boats with YJ-8 missiles.

Based on the strategic and tactical requirements described in the order, the Third Research Academy initiated work to modify the missile and to develop a weapon system for the boats. Before the end of 1984, four missiles were successfully launched from the boats to evaluate the performance and coordination of the onboard weapon system. During this period, a meeting was held to prepare for the YJ-8 design finalization test. Technical conditions for finalizing the design of the missile were defined and a test outline was approved. All units began to prepare for the test to finalize its design according to this outline. At the Third Research Academy, its technical staff, workers, and leading officials worked hard night and day in order to speed up the development of the YJ-8. They pinpointed causes and eliminated problems to overcome numerous hurdles. Despite suffering from cancer, Assistant Manager Shi Fenglou [0670 7364 2869] of the 239th Plant still insisted on conducting tests himself to set an example until the day he died.

(4) Development of YJ-8 Fire-Control System

The design of the YJ-8 is such that it can either be carried by an aircraft or be launched from a vessel or a submarine on the surface. Nevertheless, a different fire control system is required when the carrier is different. The fire control system to be installed on the Model 24 boat had to be reliable yet had to be developed in a short period of time with limited funds. The command panel was the center of the control system. It was also a key piece of equipment for the Model 24 boat. On the basis of the existing electromechanical command panel, the

design department of the Third Research Academy modified certain parts of the equipment. After going through a series of environmental tests, the command panel was successfully modified in time for installation on the boat.

The storage and transport container is an important component of the weapon system. By studying a variety of technical issues such as load, structural strength, storage conditions, control technology and rigidity coordination between the missile and the storage container, the 359th Institute of the Third Research Academy solved a number of problems, such as the exhaust of and protection from the combustion gas when the missile was launched from the container, transition from transport and launch attitude, and safety and reliability of the launch, to ensure the launch attitude and an excellent environment for missile transport. During the development process, Technical Director Lu Zuochen [0712 1563 5256] and his technical staff and workers of the institute worked as a team to improve the design and conduct repeated tests. It was the first storage and transport container successfully developed in China.

The main task to retrofit the boat was to remove the existing launch device and to replace it with the storage and transport container and support for the YJ-8, to install the necessary cable and equipment, and to inspect and repair the boat. Under the coordinated effort of the 4805 Plant, the 701st Institute of the Seventh Research Academy and the Third Research Academy, the boat was successfully retrofitted in 1982. After several launch tests, the plan to equip the Model 24 boat with YJ-8 missiles was found to be correct and all strategic and tactical specifications were met.

(5) Design Finalization Tests of the YJ-8 Missile

In October and November 1984, design finalization tests of the YJ-8 installed on the Model 24 boat were conducted on water at the Liaoxi Missile Test Range. While the first missile hit the target, the fuse malfunctioned. The two missiles that followed fell in the water short of the target due to equipment failure on the missile. The test was temporarily halted pending an analysis of tne cause. The failure analysis and proposed corrective measures received a great deal of attention from the National Defense Science, Technology & Industry Commission. Commissioner Chen Bin [7115 1755] and Associate Commissioners Zou Jiahua [6760 1367 5478] and Nie Li [5119 0500] raise specific requirements. Science and Technology Commission Vice Minister Xie Guang [6200 0342] attended the failure analysis meeting at the Third Research Academy to find causes and failed components. Technicians at the Liaoxi Missile Test Range, such as Jia Jiali [6328 1367 3829] and Gu Xixia [7357 1585 7209], believed that poor component reliability and damage to control elements due to hostile operating environment were responsible for the failure. In addition, the overall missile design had to be thoroughly examined. They also made certain recommendations concerning the primary control algorithm. Since then, by way of modification and testing, five major improvements have been made to reduce vibration and eliminate potential interfering factors during stage separation. In April and May 1985, the modified YJ-8 missile was test-launched from a surfaced submarine at the Liaoxi Missile Test Range. The result showed that the improvements made were correct and the test was a success.

In September 1985, the design finalization test for the YJ-8 on the Model 24 boat was reorganized at the Liaoxi Missile Test Range. It was primarily to evaluate the killing power of the warhead at long, medium and short range and with two simultaneously launched missiles and the performance of the onboard equipment and the entire weapon system during combat. All relevant departments were very much concerned about the outcome of this test. A very thorough deployment was arranged from organization to protective measures. Commander Wang Huique [3769 1920 1952] of the Naval Test Base was often on site to study and resolve problems encountered in the preparation. As a result of the combined effort of the team organized by Chief Designer Yao Shaofu and Assembly Designer Liu Qingmei [0419 1987 2812], the preparation went well. In this test, six missiles were launched and all were direct hits. One warhead that made a direct hit on the target ship, an old frigate, penetrated the side and then exploded. The explosion tore up a portion of the deck and set the ship afire for over 10 hours. It later sank under tow. The successful completion of the design finalization test of the YJ-8 marked a new chapter in missile testing conducted by the Navy.

The YJ-8 was the second generation anti-ship missile developed by the Chinese. It employed advanced technologies such as solid rocket engines and launch container. It is capable of flying over water at an ultralow altitude, has a strong penetration power and high accuracy, can be deployed for a number of applications and is downsized. Its major characteristics are comparable to those of its counterparts worldwide. The design of the YJ-8 was finalized in 1987 and it was given the special national science and technology progress award in 1988.

In order to expand the combat range of conventional submarines and to acquire experience in order to facilitate a transition to underwater launch of missiles from a submarine, the Navy proposed to deploy the YJ-8 on conventional submarines to the Chief of Staff Command and the National Defense Office as early as 1977. In January 1981, the request was granted. The design was then validated at the Third Research Academy and a plan for the missile system was proposed. Based on the technical level at the time, it decided to use a medium-scale-integrated-circuit computer to simultaneously control the firing of missiles and torpedoes. After the plan was approved by the Seventh Ministry of Machine Building, the Navy and the Sixth Ministry of Machine Building, the submarine was launched in 1982 as a result of the hard work put in by all units concerned. The submarine-based YJ-8 missile system was then successfully flight tested.

In June 1982, the Chief of Staff Command and the National Defense Office decided to equip frigates with the YJ-8 as a shipboard missile system. The frigate was built by the Hudong Shipyard and the development of the onboard missile system was the responsibility of the Third Research Academy. In 1983, various units proceeded with the development work. A microcomputer-based general-purpose command panel was employed. It had the capability to launch across a sector to make the weapon system more effective. In 1985, the weapon system was placed on line for testing. In September 1987, a test launch of the frigate-based YJ-8 missile took place. Two missiles both scored direct hits to successfully wrap up the test of the ship-based YJ-8 missile.

The successful development of the small multi-purpose YJ-8 missile enabled China to create a series of second-generation anti-ship missiles. Its advanced performance, flexibility and maneuverability in combat, ease of maintenance, reliability and wide range of applicability made it very popular among all units in the field. Since then, this missile has been continuously improved and modified to fit a variety of ships, aircraft and vehicles.

(6) The SY-2 Solid Propellant Ship-to-Ship Missile

The Nanchang Aircraft Company began its development of the SY-2 liquid propellant rocket engine ship-to-ship missile in the early 1970s. After a few years of effort, two telemetry missiles were launched on land at the Liaoxi Missile Test Range and the overall design of the missile was found to be rational. In December 1975, on the basis of the request from the Navy to shift the development of the SY-2 toward downsizing, ultralow altitude capability, and solid rocket engines, the Nanchang Aircraft Company began its proof of concept work on the SY-2 solid propellant ship-to-ship missile.

In August 1984, the National Defense Science, Technology & Industry Commission included the SY-2 solid propellant ship-to-ship missile in the defense technology plan for the Seventh 5-Year Plan. Some experience gained in the development of the SY-2 liquid propellant rocket engine was applied to the development of the SY-2 solid propellant missile. Emphasis was placed on theoretical calculation and ground testing to produce a reliable design. In order to strengthen the responsibility system, a designer system was established with the approval of the Ministry of Aerospace Industry. Peng Lisheng was the chief designer and Zuo Chong [1563 6850], Zhang Ju [1728 3818], and Wen Yukun [3306 5148 0981] were the associate chief designers.

The main focus in the development of the SY-2 solid propellant missile was to improve the missile. Its ground equipment, fire control system and launch pad are compatible to those of the SY-1 and SY-1A. The fact that the three missile models must share the same equipment, system, and launch pad makes the development work that much more difficult. The longitudinal guidance algorithm for the SY-2 solid propellant missile was redesigned. Through coordination between the radar and the command panel to hit a pre-determined target, its accuracy was improved. Redundancy was used in a portion of the missile and its fire control system. In terms of the booster, by selecting an appropriate charge, the procedure was simplified and the precision of the thrust axis was improved. As for the engine, the use of a free loading charge improved its reliability and storability. More explosive is packed in the warhead to enhance its armor-piercing capability to allow it to destroy heavily-armored large and medium-sized surface vessels.

In August 1984, the design of the overall assembly of the SY-2 began. In 1988, the telemetry missile test was completed. In June 1989, the first design finalization was conducted. The test was terminated by the Navy due to repeated engine failure. A rigorous failure analysis was conducted by the Nanchang Aircraft Company. It adopted 12 improvements to enhance reliability and environmental adaptability. In October of the same year, the Ministry of Aerospace Industry and the Navy agreed to proceed with the second design finalization test. Vice Minister He Wenzhi [0149 2429 3112] provided valuable opinions on quality and organization related to the test and arrived at the test site in person to inspect the preparation work. In December 1989, the design finalization test for the SY-2 solid propellant missile was completed at the Liaoxi Missile Test Range of the Naval Test Base with a record of 5 out 7.

(7) Low-Altitude Supersonic Anti-Ship Missiles

The transition from subsonic to supersonic anti-ship missiles is a giant leap forward. To develop a low-altitude, supersonic anti-ship missile, it is necessary to solve the problems associated with a high specific impulse ram engine.

A ram engine is simple in structure, has a high specific impulse, is lightweight and has no moving parts. It is an ideal power source for a low-altitude supersonic anti-ship missile. As early as April 1965, Qian Xuesen and Liang Shoupan suggested the development of a ram engine. Based on this suggestion, the 31st Institute of the Third Research Academy conducted some advanced research on a ram engine for an anti-ship missile. After repeated investigations and numerous ground tests over many years, technical issues such as low-temperature start-up, matching the pre-combustion chamber to the combustion chamber, combustion oscillation, melting of the flame stabilizer and matching the fuel supply system to the engine, were resolved. In 1969, under the direction of Bao Keming and Liu Xingzhou [0491 5281 3166], a ram engine was developed using the results of advanced research. They conducted over 600 ground tests to overcome technical hurdles to finalize the design for ground tests. Then, a series of products was developed to serve as ram engines for a variety of supersonic flying vehicles with different requirements.

In September 1971, the Navy approved the development of a ram engine for a low-altitude supersonic missile.

This missile had a two-stage power device. The first stage consisted of two parallel solid propellant booster rockets. The second stage consisted of two ram engines on either side of the missile body. A small monopulse terminal guidance radar with excellent interference resistance was installed on board. The control system included both automatic control and self-guidance. The missile had a number of unique characteristics such as low altitude, supersonic speeds, high penetration capability, small size, light weight, strong hitting power, low cost, and a wide range of carriers.

This low-altitude supersonic missile was developed without much prior experience and without sufficient advanced research. It was also adversely affected by the "Cultural Revolution." The work was interrupted several times. Tests of automatic control missiles began in 1978. The two ram engines were successfully ignited in mid-air simultaneously. However, we encountered problems such as deviation from course and large pitch angle. Chief Designer Shen Shijin [3088 0013 6930] and Associate Chief Designer Huang Ruisong [7806 3843 2646] went to the test site to solve a large number of problems with the technical staff. For instance, a closed-loop radio altimeter was chosen to stabilize the flight of the missile at the same altitude. The unique patterns associated with a supersonic vehicle became known as a result of the tests. Furthermore, a great deal of work was done to perfect the aerodynamic profile, improve its structure and raise its reliability. The self-guidance missile test conducted in 1985 was essentially a success. In addition, the terminal guidance radar—a weak link at supersonic speeds—was replaced with a mono-planar terminal guidance radar. This was followed by two additional tests launched from land. Both resulted in direct hits. Thus, the ground test phase was successfully completed. This demonstrated that China had the technology needed to develop low-altitude, supersonic anti-ship missiles and had begun to apply it to develop both ship-based and airborne supersonic anti-ship missiles.

Since the late 1950s, China has successfully developed a variety of ship-to-ship, shore-to-ship and air-to-ship missiles and established a research, test, and production system for anti-ship missiles. A highly capable and experienced technical team has been established. In the development of anti-ship missiles, China has developed a way that combines research, design, prototype construction, testing and production of a specific series of missile. China will make full use of its experience, pick its own targets, keep track of key technological advances worldwide and develop a series of multi-purpose anti-ship missiles that meet its own needs.

Chapter XX. Naval Vessels

The warship is the major weapon to execute combat and protection missions either on water or under water. It includes a variety of vessels such as the submarine, destroyer, frigate, torpedo boat, missile boat, subchaser and auxiliary vessels. The development of the modern warship and its weapons is highly sophisticated and complex in nature and is a large-scale system engineering undertaking.

Since the founding of the People's Republic of China, owing to the concern of the Chinese Communist Party Central, the State Council, and the Central Military Commission and the hard work over a period of four decades, a relatively comprehensive development and production system has been established for the development of naval vessels and weapons. It followed a path starting from manufacturing transfer, duplication, improvement and gradually to independent development. Finally, technical breakthroughs were made to provide significant contributions to the construction of naval equipment.

Section 1. Overview

(1) From Manufacturing, Transfer, and a Preliminary Foundation

In August 1950, the Navy presented a plan to rapidly build up a light combat force that was focused on naval aviation, submarines and torpedo boats, and then establish other services. To build naval vessels, the Ministry of Heavy Industry established the Bureau of Shipbuilding Industry in Shanghai. At the same time, the Navy also established its own shipbuilding department to oversee the repair and building of all naval vessels. On the basis of the technical assistance agreement signed by China and the USSR in June 1953, it also began the manufacturing transfer of five different types of vessels.

In 1954, the Bureau of Shipbuilding Industry Management established a branch office of ship design in Shanghai (it was renamed the First Prototype Ship Product Design Office in 1955). Xin Wei [6580 3837] was the office director and Li Siyao [2621 0843 1031] was the chief engineer. This office was in charge of all technical issues associated with the manufacturing transfer of a frigate, a medium torpedo submarine, a mine sweeper, a large subchaser and a torpedo boat from the USSR. It was responsible for handling all problems encountered in production. In addition, the Bureau of Shipbuilding Industry Management was also responsible for the renovation and expansion of the six yards and two work sites engaged in the production of those five types of vessels. From 1955 to 1959, under the direction of Russian advisors, these yards assembled over 100 vessels. The manufacturing transfer of these five types helped China's shipbuilding industry train technical people, renovate its major shipyards, and lay a preliminary foundation for the development of military vessels.

Parallel to our effort to assemble Soviet vessels, we also began to organize research institutions and testing facilities for shipbuilding in order to meet future needs of the Navy. In 1954, the First Ministry of Machine Building established the Ship Model Institute to be led by Xin Yixin [6580 0001 1800] and Fang Wenjun [2455 2429 0971]. In 1957, it was expanded to become the Institute

of Ship Science under the First Ministry of Machine Building and the Ministry of Transportation. In 1958, the First Ministry of Machine Building established four research institutes including the Ship Design Institute and Ship Steam Turbine Institute. Jia Shengde [6328 4141 1795] was the deputy director of the Ship Design Institute and Sa Benxin [5646 2609 1823] was its chief engineer. After 1958 the Navy established four research institutes for shipbuilding, surface weapon, sonar, and navigation. In 1959, the Navy established the Department of Science and Technology to direct all research activities associated with naval vessels and weapons. Yu Xiaohong [0060 4562 5725] was the department head and Jiang Yong [3068 0516] was its political commissar. Shipbuilding departments and naval weapon special fields were also established at higher learning institutions and military engineering institutes in Shanghai, Dalian, Xian, and Wuhan to provide professional training.

On 4 February 1959, China and the USSR signed the "Agreement To Assist the People's Republic of China To Manufacture Naval Vessels in China" (or the "February 4th Agreement"). The agreement allowed China to pay for the transfer of complete sets of technical drawings and data and the rights to manufacture certain equipment associated with a conventional missile submarine, an improved conventional submarine and two models of missile boats, as well as drawings and information needed to duplicate a hydrofoil torpedo boat and its weapon system. In order to grasp shipboard missile technology, in a report to the Central Military Commission, the Naval Party Committee proposed a policy to continuously upgrade conventional equipment with missiles and to focus on the development of submarines and other medium- and small-sized vessels. This clarified the direction of naval weapons development and accelerated the transition from imitation to independent development. In 1960, the Bureau of Shipbuilding Management was placed under the jurisdiction of the Third Ministry of Machine Building. The military vessel design laboratory of the Ship Design Institute was expanded into seven laboratories, and included subjects such as torpedo and navigation instrumentation. Furthermore, it began to construct a large ship model hydrodynamics test base at Wuxi to lay down a solid foundation for future technical work in shipbuilding.

(2) Successful Development of First Generation of Naval Vessels, Weaponry, and Equipment

In August 1960, just as shipyards and factories were geared up for the production of the five vessel types and associated weaponry covered by the "February 4th Agreement," the Soviet advisors were withdrawn by their government, cutting off technical support and equipment supply. China was determined to establish its own research institutions to build its own ship technology and industry in order to independently develop its own naval vessels and weapons. In June 1961, the Chinese Communist Party Central approved the establishment of the Academy of Ship Research (the 7th Research Academy of the Ministry of National Defense, or the 7th Research Academy), based on the resources in the field of ship research and design at the 1st and 3rd Ministry of Machine Building and the Navy, to be responsible for the research and design of naval vessels, weapons and equipment and for solving technical issues encountered. Since the founding of the 7th Research Academy, a variety of institutes for total ship assembly, principles and performance, main machinery, auxiliary engines, nuclear submarines and weapons and equipment, as well as an overall design validation department, were created. In 1963, after the 6th Ministry of Machine Building was created, research institutes for shipbuilding, engine construction, instrumentation, techniques and standards, and intelligence were established. The establishment of these research institutions and the construction of a number of large-scale test basins, laboratories and test facilities in the 1960s further provided the necessary conditions to permit China to produce those imitated ships and to develop naval vessels and weaponry independently. The 7th Research Academy concentrated 79 percent of its technical resources to work closely with factories to complete the assembly and imitation of torpedo boats, missile boats, missile submarines, and weapons such as torpedoes with domestic materials and production equipment. By the late 1960s, China was producing conventional submarines, torpedoes, and missile boats with domestic materials and equipment. Moreover, it also developed a number of mines, depth charges, shipboard guns and mine sweeping equipment. It independently designed several surface vessels, including an anti-submarine frigate.

In the mid-1960s, the 7th Research Academy of the 6th Ministry of Machine Building began to develop a number of first-generation vessels including a nuclear powered submarine, a long-range survey ship, a missile destroyer, a missile frigate and a medium torpedo submarine. It also began to develop a variety of weapons such as the self-guided torpedo, modern mines, rocket depth charges and shipboard guns. In order to meet the needs in the development of our own first-generation vessels, the government support the 7th Research Academy to continue its control over ship-related research. By the end of the 1970s, a complete system ranging from research, design and production, from total ship assembly to materials, equipment and weaponry, from testing to maintenance, together with a nationwide collaboration network, was built up to essentially complete the development of the first generation of vessels and weapons.

(3) Creating a New Stage for Naval Vessel Development

In the early 1980s, in accordance with the national defense plan, the 6th Ministry of Machine Building arranged the development of all naval vessels and

weapons. It insisted on sticking to the policy of shortening the development cycle, focusing on key programs, stressing research, and accelerating renovation. It started by improving the tactical performance of existing vessels and weaponry and then shifted the focus to the development of a new generation of highly automated vessels and weapons that are more resistant to air, submarine and missile attack and electronic warfare. It took full advantage of the open door opportunity to import the necessary technology to strengthen our advanced research activities in order to sustain our continuous development work. By the late 1980s, as the China Shipbuilding Industry Corporation completed the development and modification of the entire first generation of naval vessels and equipment, it began to organize the development of the second generation of vessels and weapons, proceeded with the testing of conventional and nuclear-powered submarines, and finished the major retrofitting of the "Wangyuan," a survey ship. This marked a new stage for the development of naval vessels and weaponry.

Section 2. Conventional Submarines

A conventional submarine is a vessel powered by diesel engines and a series of batteries, that can move and fight under water. It can be well concealed, is able to launch a powerful surprise attack, is relatively self-sufficient and has a long-cruising range. It is capable of conducting combat activities independently at sea for an extended period of time. It is a major combat vessel in the Chinese Navy.

(1) Manufacturing Transfer and Improvement of Conventional Submarines

In 1953, manufacturing transfer of medium-size conventional Soviet submarines began at the Jiangnan and Wuchang shipyards, respectively. Work on the first submarine began in April 1954 at Jiangnan and it was launched in March 1956. In October 1957, the job was completed. Through this manufacturing transfer, our shipbuilding technology was advanced, a submarine production line was established, a technical staff and workers were trained, and organization and management experience was gained. It was the beginning of submarine production in China.

In 1959, China began to produce an improved medium-size conventional submarine and a conventional missile-carrying submarine transferred from the USSR. In order to speed up the process enabling the manufacture of these submarines domestically, particular attention was paid to the design drawings and information concerning major equipment on board the submarine. The importation of equipment and materials was minimized. Anything that could be built in China was no longer purchased abroad. After the USSR pulled its advisors and terminated its aid, China decided to compress other existing naval equipment development programs and concentrate its resources on the construction of these two submarines. Medium-sized conventional submarines were being built at the Jiangnan and Wuchang shipyards. The first submarine was completed in December 1965 at Jiangnan. Later, it was produced at the Huangpu and Peiling shipyards and became the largest number submarine model ever built in China. The conventional missile-carrying submarine built by the Dalian Shipyard was completed in August 1966.

Because the material and equipment provided by the USSR became even more incomplete with time, domestic materials and equipment were needed to build these submarines. To this end, as it organized the construction of the two submarines, the government also took charge of the production of the necessary materials and equipment to make sure that the need in subsequent submarine production could be met. In addition, major technical issues such as the welding of special steel, propeller cavitation erosion, and reinforcement of the hull structure were also resolved. By the early 1970s, the manufacturing transfer of the two submarines was successfully completed and all the onboard equipment and materials were produced domestically. Furthermore, there were improvements on items such as the missile launcher and air conditioning and refrigeration capacity on board conventional submarines. In 1976, under the leadership of Li Jianqiu [2621 1696 3808] and Yang Huansheng [2799 3562 3932] of the 701st Research Institute, conventional submarines were redesigned to accommodate anti-ship missiles. Feng Longyun [7458 7893 0061] was in charge of the design of pressure-resistant missile storage containers. Modification of the launcher began at the Wuchang Shipyard in 1980. In 1985, missiles were successfully launched from submarines at sea. Since the mid-1980s, development personnel have lowered the noise level inside this model submarine by as much as 12 dB relative to its original level. This increased its concealability and expanded the effective range of its sonar.

(2) Independent Development of Conventional Submarines

In 1967, the Central Military Commission approved the development of the first-generation medium-sized conventional torpedo-carrying submarine. The Navy imposed higher tactical technical specifications. The underwater speed was increased by 40 percent relative to that of the duplicated Soviet submarine. Hence, the guiding principle in the development of the first-generation medium-sized conventional submarine was to make breakthroughs in key technical areas such as underwater speed based on the experience acquired in the duplication and improvement process and on our existing technology base. Under the leadership of Zhang Nanru [1728 0589 1172], Yang Huansheng and Li Lianyou [2621 6647 2589], the 701st Research Institute that was in charge of the design of this medium-sized conventional submarine consistently gave priority to ensuring and improving its underwater navigation characteristics. First, the profile of the submarine was improved to reduce drag. On the basis of a great deal of

experimental work done at the 702nd Research Institute, a straight bow and sharp stern profiles were adopted, the aspect ratio of the submarine was adjusted, the valves and pipes on the upper deck were rearranged to reduce the size and width of the deck, and the shape and layout of the water holes were improved to minimize drag. Next, a high-power electric motor and its corresponding controls were designed by the 712th Research Institute and manufactured by Xiantan Electric Motor Factory. A medium-speed diesel engine built by the Shanxi Diesel Engine Factory was selected. Furthermore, the number of sets of batteries was increased to four to increase the output of the underwater power supply. In addition, a high-efficiency propeller was designed. Because these measures were taken in the overall design, with minimal increase in displacement as compared to that of the duplicated Soviet submarine, the new design doubled its underwater propulsion and battery storage capacity to ensure the speed of the submarine.

The first-generation medium-size conventional submarine was built at the Wuchang Shipyard. Under the leadership of Wei Xumin [7614 4872 3046], the construction of the first vessel began in October 1969. It was launched in July 1971 and was delivered in April 1974. The first vessel built at Jiangnan Shipyard was completed in November 1974. Afterward, Wuchang made design modifications to the second submarine based on problems encountered during the shakedown cruise of the first submarine. It significantly improved the performance of the second submarine. In December 1983, this independently developed first-generation conventional torpedo-carrying submarine was appraised at the national level. Its speed, maneuverability, seaworthiness, submerged cruising radius and submerged noise level were found to be considerably better than those of the improved model of the duplicated medium-size conventional torpedo submarine. The equipment on board was found to be essentially stable and reliable.

In order to meet the challenge of modern warfare, the 719th Research Institute again began to develop a new generation of conventional submarines. New technology was adopted to develop a more advanced wire-guided torpedo, a new torpedo launcher, and digital sonar and display equipment.

In addition, to meet sea rescue requirements, a 30-ton deep-sea rescue submarine was jointly developed by Wuchang Shipyard, Harbin Institute of Shipbuilding, Shanghai Jiaotong University, Central China Institute of Engineering and the Naval Institute of Medicine in the early 1970s. In 1980, the first vessel was launched at Wuchang Shipyard. It underwent five trials to conduct a variety of tests, including underwater docking dry rescue, open compartment wet rescue and great depth diving. The rescue submarine was found to meet all design specifications and is capable of performing a level-3 rescue mission. It filled a void in deep-sea rescue for China.

Section 3. Surface Ships

Surface ships are an important part of naval vessels and weaponry. China primarily developed destroyers, frigates, subchasers, torpedo and missile boats, mine warfare vessels, and landing craft.

(1) Destroyers

A destroyer is a powerful surface striking force, has a long cruising radius, and has substantial anti-submarine and anti-aircraft capability. Its primary mission is to attack enemy submarines and surface vessels, to support landing troops, and to provide escort.

(i) Development of the first-generation missile destroyer

The 7th Research Academy began to investigate the overall design of and to conduct advanced research on a missile destroyer in the late 1950s. In the mid 1960s, in order to provide escort and protection for ICBM testing over water, the Central Military Commission approved the development of the first-generation missile destroyer. The 701st Institute of the 7th Research Academy was responsible for its overall design. Li Fuli [2621 1788 4409] and Pan Jinfu [3382 6975 5346] were in charge of the design work. A plan was chosen after validation, advanced research, and preliminary design. Its standard displacement is over 3,000 tons. A high-performance steam engine was selected. Its main weapons systems include two triple ship-to-ship missile launchers, 130mm and 57mm guns, and two rocket depth charge launchers with 12 tubes each. It was also equipped with a variety of observation and command and control equipment such as sonar, radar, and communications and navigation systems.

In June 1967, the State Planning Commission, the National Defense Office, and the National Defense Science Commission reviewed and approved the technical design for the first-generation missile destroyer. Construction design and equipment development ensued immediately after the plan was approved. In 1968, the construction of the first prototype ship began at Dalian Shipyard. Factories and research institutions under the jurisdiction of 22 provinces and cities and industrial ministries were involved in the supply of 732 items and 1,240 pieces of equipment, including the development of over 110 pieces of new equipment. Building a missile destroyer is a highly complex system engineering project. During the ship construction and equipment development, our personnel worked very hard to overcome numerous technical hurdles.

Solving onboard missile problems.

Several studies were conducted by the 701st Institute, 713th Institute and the Third Research Academy of the 7th Ministry of Machine Building to demonstrate the feasibility of mounting missiles on the ship. In December 1968, the research and design department, in conjunction with Dalian Shipyard, temporarily installed ship-to-ship missiles on an active destroyer to conduct a

variety of tests to measure important factors such as missile attitude, surface noise spectrum, combustion gas flow pressure field, surface structure stress and ship movement. The data and experience obtained provided first-hand information to solve problems associated with mounting ship-to-ship missiles. The development department also did a great deal of work on the missile launcher. Based on Navy requirements and by comparing various schemes, a triangular triple launcher was selected. The missiles were to be directly loaded by crane. Xie Xianzheng [6200 2009 4545] and Yao Yuecong [1202 6460 3222] of the 713th Institute were responsible for its design. Furthermore, it broke from the tradition of separating the launcher from the loading device and adopted a design that is compact, easy to operate, and quick to reload. By way of the research and testing activities described above, key technical issues associated with installing missiles on board were also smoothly resolved.

The first prototype ship was delivered to the Navy by Dalian Shipyard in December 1971. In September 1973, the first missile flight test was conducted at the Naval Test Base. Both single and double missile launches were successful. In the mid-1970s, the destroyer missile launcher design was appraised by the Navy and the 6th Ministry of Machine Building after which it was modified based on Navy requirements. The missile storage environment and operating conditions were improved. It was made more adaptable to rough seas and more resistant to nuclear explosion.

Improvement of main boiler air intake and smoke exhaust.

The first-generation missile destroyer was fitted with two high-power steam turbines, four boilers, 18 auxiliary steam engines and 27 auxiliary electric motors. It was a difficult task to lay them out rationally in a crowded engine room and make them work in harmony. The initial air intake design had too much resistance and the blowers for the two turbines were too close to supply enough air to the boilers. The 20 fuel injectors could not burn completely. Hence, the main engine could not reach its rated maximum rpm and that affected the cruising speed. Despite numerous modifications made by technical staff at the Dalian and Zhonghua shipyards, the problem was not fundamentally solved. With the cooperation of Zhonghua Shipyard and Hangzhou Steam Turbine Factory, the 701st Institute fabricated several air duct models to conduct resistance tests. The diversion cap profile and blower spacing were altered to minimize vortex loss. Ideal results were obtained through wind tunnel tests. Then, tests were conducted at the blower factory using the actual duct to optimize the design. It solved the problem that both blowers are fighting for the same air to enable all fuel injectors to burn completely. The cruising speed of the ship also met design specifications.

Development of new acoustic and radar equipment.

The first-generation missile destroyer was equipped with a variety of special electronic devices. The technical staff at the 706 Institute, the 726 Plant and the 461 Plant jointly developed the SJD-11 long-range spherical nose bow detector sonar and the SJD-4 attack sonar. Eleven large-scale tests were done on the SJD-11 sonar. In 1971, in actual shipboard tests, this sonar was capable of effectively picking up enemy submarines in poor hydrological conditions at 18 knots. The coordinated action of the sonar, the rocket depth charge launcher and the command panel can execute the mission of searching for and attacking enemy submarines. After over a decade of effort, the 724th Institute of the 7th Research Academy made a breakthrough in dual beam planar array antenna and solid state forward wave transmitter technology. Using a computer-driven frequency agile and digital moving target display system, a new three-axis phase scanning air alert radar was developed. This radar had advantages such as high interference resistance, power, high efficiency, strong signal adaptability, and compact structure. It was at an advanced domestic level and was given a first-place national science and technology advancement award.

Wave endurance test.

In order to further evaluate the quality of the first medium-sized missile destroyers built by the Dalian, Guangzhou, and Zhonghua shipyards, on the basis of over 200 successful cruising tests in the North China Sea, South China Sea and East China Sea conducted by their respective shipyards, a 5-hour-20-minute wave endurance test was conducted 450 meters deep in rough seas east of Hainan Island and north of Xisha Islands in December 1975. The maximum wave at the bow was 6 meters. The tests were conducted under a variety of conditions, including different angles between the wave and the heading, different cruising speeds, and with and without using the fin. In a wave test, the ship was accelerated to 28 knots for a half hour. The bow was never under water and the propeller never broke the surface. Various electrical equipment and weapons passed the test. This series of tests proved that the first prototype ships were capable of meeting all design specifications.

Upon completion of the first prototypes of the first-generation missile destroyer, the 6th Ministry of Machine Building was organizing its resources to solve remaining issues while preparing for the production of the ship and engaging in the evaluation and design finalization of certain weapon systems. In 1975, the production design of the ship was finalized.

(ii) Improvement of the first-generation destroyer

To meet the challenge in modern warfare, with the approval of the State Council and the Central Military Commission, the first-generation destroyer was modernized and improved in the early 1980s as the first step to develop a new generation of destroyers. In 1983, the 7th Research Academy pulled resources from the 701st,

709th, 716th and 724th institutes to perform proof-of-concept studies to improve shipboard weaponry on the first-generation missile destroyers. The 701st Institute was designated as the leading institution responsible for all major technical issues concerning combat systems on the destroyer. The plan was to base the technical specifications of various electronic and weapons systems on the requirements of the ship and its combat system. Coordination of different weapons was stressed. It was a change from the past practice in which equipment was defined first and then combat information command system developed later. A system engineering approach was used in the development of the combat information and command system. With the help of all parties involved, the effort to improve the main equipment of the combat information and command system began in December 1986. It was successfully linked and tested on land and then installed on the missile destroyers.

In 1987, the modified version of the first-generation missile destroyer began to be built at Dalian Shipyard. Due to the two major technical measures mentioned above, the weaponry and living quarters on board were substantially improved. In particular, resistance against electronic warfare is enhanced and degree of automation of combat command is raised. The modified missile destroyer was completed and delivered to the Navy in December 1989.

(iii) Developing a new generation of destroyer

As the 7th Research Academy was engaged in modifying the first-generation destroyer, it began to develop a new generation of missile destroyer. Prior to this, the appropriate authority was considering modifying the first-generation destroyer with a foreign nation. Due to various reasons, the arrangement fell through. The Central Military Commission decided to switch the funds earmarked for the foreign deal to the appropriate department for development use. The National Defense Science, Technology & Industry Commission later laid down a development plan with the China Shipbuilding Corporation and other relevant organizations. The new destroyer would be equipped with an even more automated and more responsive combat information and command system. The system had the capability to process data and information gathered by the shipboard long-range alert radar, sonar, electronic surveillance devices, and friend-or-foe identification detector on a real-time basis. Furthermore, its anti-aircraft, anti-submarine, anti-missile and anti-electronic warfare capability would be enhanced significantly.

(2) Frigates

A frigate is a medium- to small-size vessel that is primarily armed with underwater weaponry, guns, and missiles. Its primary missions include convoy escorting, anti-submarine warfare, anti-aircraft warfare, deployment of mines, patrol, alert, and support of landing forces.

In the early 1950s, the Navy established the Department of Ship Repair and Construction to design the 53-A coastal patrol boat under the direction of Chief Designer Xu Xhenqi [1776 2182 3825]. Later, the second product design office of the Bureau of Shipbuilding Industry designed the 55-A coastal patrol boat based on drawings supplied by Russian advisors. It was put into production at the Qiuxin, Jiangnan, and Hudong shipyards. These patrol boats played a vital role in the liberation of the coastal islands. Later on, in the 1960s, it designed the Model 62 high-speed frigate with top speeds up to 30 knots to meet certain requirements. These frigates were the early surface combat vessels independently developed in China.

In 1962, the 701st Institute was in charge of the overall design of the Model 65 frigate. Under the leadership of Chief Designer Yu Boliang [0205 0130 5328], the ship adopted a design with a long forward section not only to have space for the main engines but also to have more room and a larger deck. In addition, it also provides more stability at large angles of inclination and better hull rigidity. In 1963, the first ship was built at the Jiangnan Shipyard. In 1965, construction of the second ship began at the Guangzhou Shipyard. Both vessels were completed and put in service in 1966. Over the years, the Model 65 frigate has undertaken numerous long voyages and survived level-12 typhoons. It has safely sailed over 100,000 nautical miles. Its successful development improved the technical standard of surface vessels independently developed in China and laid a solid foundation for the development of missile frigates in the future.

In the mid-1960s, the 701st Institute began to develop a surface-to-air missile frigate. The objective was to attack enemy vessels at close and medium ranges with missiles and guns and defend against air attack at the same time. With the cooperation of all institutes and factories involved, the 701st Institute conducted design research of the vessel from the second half of 1966 through the first half of 1969. The combined steam and diesel power source was changed to an all-diesel system. In addition, ship models were tested and technical coordination between ship and equipment investigated. In September 1969, a consolidated design group comprised of technical personnel from the 701st Institute, the Hudong Shipyard, and end-users in the Navy was created to carry out the design work at the Hudong Shipyard. In the 1970s the frigate was essentially completed by Hudong. Nevertheless, development of the ship-to-air missile and the main guns was delayed. Later, since the Navy was in desperate need, the ship-to-air missile frigate was changed to a ship-to-ship missile frigate. The twin 100mm guns were replaced by single 100mm guns. Hudong Shipyard was put in charge of its design and construction based on the model developed for the ship-to-air missile frigate. In 1976, the ship-to-ship missile frigate was completed. The development of the missile frigate went through a difficult path. Eventually, the urgent need of the Navy for a missile frigate was met.

In the early 1980s, the twin 100mm gun was successfully developed and installed on the anti-ship missile frigate. It was renamed the anti-ship-I missile frigate. In 1983, the anti-ship-I missile frigate was further improved by Hudong, the system engineering department of the China Shipbuilding Industry Corporation and the Third Research Academy of the Ministry of Aerospace Industry. Primarily, the two rotating twin SY-1 missile launchers were replaced with eight fixed YJ-8 missile launchers, a simple combat information command system was added to the combat command center, electronic warfare equipment was installed, and the entire ship was retrofitted to a sealed type. The improved frigate was named the anti-ship-II missile frigate. In 1988, after the successful development of the anti-aircraft missile, the Navy asked the 701st Institute to design a combined anti-ship and anti-aircraft missile frigate. Xie Xianzhag and Li Jingtang [2621 2417 1016] of the 713th Institute designed a special twin ship-to-air missile launcher complete with its own missile storage facility. Then, the development of an anti-aircraft missile frigate originally proposed in the 1960s was accomplished. However, its tactical specifications are much higher than those originally proposed. In particular, the Hudong Shipyard worked hard to upgrade continuously weaponry and equipment on this vessel to enhance the combat capability of the ship and acquired considerable experience as well.

In 1986, the 708th Institute and the Guangzhou Huangpu Shipyard designed and constructed a 500-ton missile frigate that could launch a missile attack as well as perform patrol duties. It employs a shipboard combat command system and is a new generation missile frigate that China has developed.

(3) Torpedo, Missile Boats

A torpedo or missile boat is a high-speed craft or hydrofoil that uses torpedoes or missiles as its primary firepower. It is small, fast, powerful, low cost, highly mobile, very maneuverable and concealable. It is suitable to attack enemy surface vessels individually or in formation along the coast with the support of other forces. It is known as the cavalry of the sea.

In the 1950s, shipyards in Wuhu and Guangzhou produced a copy of a Soviet twin-tube torpedo boat. In 1966, the 701st Institute was responsible for developing a four-tube torpedo boat. Yan Jianti [0917 4675 7555] and Cao Guanzhong [2580 0385 0022] were the technical leaders. The first boat built by the Guijiang Shipyard in Wuzhou was delivered in September 1976. Later, the design was modified and was tested for its speed, wave endurance, torpedo fire control panel and simultaneous firing of all four torpedoes. It was proven that this independently developed four-tube torpedo boat not only had a high probability of hits but also excellent endurance in high waves.

The development of missile boats was based on our experience in the assembly, duplication and improvement of the Russian missile boat. It began in the early 1960s.

In January 1966, the Central Special Committee approved the development of a small steel-hulled missile boat. Under the direction of Hua Qiru [5363 3823 1172], the 701st Institute chose a design that could simultaneously launch two missiles and had a twin 25mm semi-automatic gun. The 713th Institute was responsible for designing the missile launcher and Wuhu Shipyard was responsible for its prototyping and production. In December 1966, Wuhu Shipyard completed the missile boat and officially handed it over to the Navy.

From 1980 to 1982, in order to meet the need to test new ship-to-ship missiles, the small steel-hulled missile boat was modified so that it could launch four ship-to-ship missiles. Since then, validation of and advanced research on various concepts of a new 300-ton assault missile boat were carried out.

(4) Subchasers

A subchaser is a light anti-submarine frigate. Its primary mission is coastal patrol, anti-submarine warfare, and escort.

In the mid-1950s, using the design drawings and the necessary materials and equipment purchased from the USSR, the first batch of subchasers was assembled at Huangpu Shipyard by workers sent down from the Qiuxin and Dalian shipyards.

In October 1959, the Navy requested that a better anti-submarine frigate be developed. The first office of the Shipbuilding Design Institute of the 1st Ministry of Machine Building was responsible for its design. Lu Yongchang [0712 3057 2490] and Ma Shoulun [7456 1343 0178] were the chief and deputy chief designer, respectively. Since the founding of the 7th Research Academy in 1961, the technical design was completed by the 701st Institute. In 1962, due to our urgent need to provide protection to shipping and fishing in the South China Sea, and considering the fact that it would be difficult for the anti-submarine frigate to pass through the Taiwan Strait after its completion, the first ship was assembled at Huangpu Shipyard in Guangzhou by workers sent down from Dalian Shipyard using parts fabricated at Dalian Shipyard. Later, the remaining fleet was constructed by Huangpu Shipyard.

An anti-submarine frigate has a propeller silencing device. It is highly adaptable to different sea conditions and is very fast. The first ship was delivered in 1963. Later, several modifications were made based on needs in the field to further enhance its performance. In February 1975, when the production design of the anti-submarine frigate was finalized, it could meet the requirements in the north and south. After years of service, the tactical performance of the ship was found to be excellent. In January 1974, two ships successfully

repelled an enemy attack in the battle of the Xisha Islands. In 1983, the 701st Institute and Qiuxin Shipyard in Shanghai again successfully developed a modified version of the frigate. Its performance was further enhanced.

(5) Mine Warfare Vessels

In 1956, the first product design office of the Bureau of Shipbuilding Industry Management of the 1st Ministry of Machine Building was responsible for the design of the first generation harbor minesweeper and Bai Juyuan [4101 1565 3293] was named chief designer. The proof of concept and design work was completed in 1958 and its construction was done at Qiuxin Shipyard. In 1962, the ship was completed, tested, evaluated and then delivered to the Navy.

In November 1967, the National Defense Office issued an order to develop a low magnetic steel hull river and harbor minesweeper. The 708th Institute was responsible for its design. The minesweeper used a new low magnetic manganese-aluminum series of steel that is available in China. Manufacturing techniques were developed to improve the degaussing of the vessel. Upon completion of its design in 1969, it was constructed by Zhonghua Shipyard. In April 1974, it was completed, tested and delivered to the Navy.

In the early 1970s, the 701st Institute, 708th Institute and the Zhonghua Shipyard jointly developed the Model 312 minesweeper which consolidated the ship and the minesweeping equipment in one unit in an attempt to combine application, design, and production. Du Yongkang [2629 3057 1660] of the East Sea Fleet was the design group leader and Liu Zhiping [0491 3112 1627] of the 701st Institute was the deputy group leader. The 708th Institute was responsible for the design work. During the development process, the team worked with dozens of factories such as the Shanghai Rectifier Plant, Shanghai Electric Works and Shanghai 23rd Radio Plant to develop special cables, cable-laying equipment and remote control devices. In a year and a half, it completed the design, construction and shakedown cruise of the 312 boat.

These three models of minesweeper removed dozens of American-made mines in the early 1970s during the Vietnam War. This demonstrated the effectiveness of the minesweepers independently developed by China. In 1976, the new-generation Model 082 consolidated harbor minesweeper was developed. The 708th Institute was responsible for the design work and Ma Jinhua [7456 6930 5478] was the chief designer. The 701st Institute was responsible for the minesweeping equipment. Jiangxin Shipyard completed the construction of this model of minesweeper and delivered them in 1987. The ship is equipped with electromagnetic, sonic, subsonic, cutting, and explosive minesweeping devices. Its effective range is several times greater than that of the Model 312. Protective measures were taken against strong impact against the hull, equipment, and personnel.

In the late 1970s, the Navy requested that a new surface minelayer be developed. In 1981, the Chief of Staff Command and the National Defense Office officially issued an order for its development. The 708th Institute was responsible for the design work and the necessary equipment was developed by other institutes in the 7th Research Academy system. Ma Jinhua was named chief designer. In 1985, all equipment was qualified on land and ship construction began at the Dalian Shipyard. In January 1981, the ship was completed, successfully tested and then delivered to the Navy. This minelayer could resupply and load mines without any pier facility. It is equipped with a large span crane. A mechanized mine transport system exists between its two decks and with horizontal and vertical motion control. A navigation command system capable of pinpointing the locations of the vessel and the mines is also on board. It is at 1980 world class level.

(6) Landing Craft

Between 1955 and 1962, China designed and constructed three different models of landing craft. In the 1970s, two models of medium landing craft capable of operating in Category II zones were successfully developed and put into production. In 1975, we began to develop the 450-ton Model 072 large landing craft to carry more powerful weapons. This vessel was designed by the 708th Institute under the direction of Chief Designer Ding Weiren [0002 3837 0117]. The Zhonghua Shipyard was responsible for its construction. To ensure high speed and capability to reach and leave the beach, the landing craft has a slender bow to reduce wave drag. A special two-section 17-meter-long folding suspension bridge was developed. The bridge is hydraulically driven and only takes 3 minutes to extend and position. The vessel has a large covered tank section; an amphibious tank be driven forward into the vessel from its stern and leave facing forward from the platform at the bow. The vessel is also equipped with a 60-ton hydraulic stern anchor, a hydraulically driven ramp and a bow door opener. The first Model 072 landing craft was completed in 1979, and passed an expanded appraisal test before it was delivered. The vessel's speed is over 20 knots. In two beach landing trials, the end of the ramp was no more than 0.8 meter under water. In actual use, the Model 072 landing craft has excellent speed, maneuverability, seakeeping quality, and landing capability. In the 1980s, China began to develop new medium and large landing craft.

Section 4. Auxiliary Vessels

(1) Ocean-Going Instrumentation Ship

An ocean-going instrumentation ship is a special ship constructed for the development of intercontinental ballistic missiles and aerospace technology.

In the mid-1960s, based on the order issued by the National Defense Science Commission, the ship design department of the 7th Ministry of Machine Building, the 7th Research Academy of the 6th Ministry of Machine Building and the appropriate test base under the National Defense Science Commission formed a team to begin proof of concept work on the onboard measurement scheme and measurement control system on an ocean-going instrumentation ship by combining their experience in application, design and production together. In addition, the 7th Research Academy pulled personnel from 10 different institutes to form the "64 Work Group." It was led by Xu Xueyan [6079 1331 1750]. Together with Shangguan Shipan [0006 1351 0013 4149] and Wang Lichun [3769 4539 2504] of the test base, they jointly proved the concept of the instrumentation ship. After years of investigation, repeated testing, and validation, the overall design of the instrumentation ship and technical schemes for its measurement and control, communication, navigation and location, recovery, and meteorological systems were finally determined.

In 1974, various units began the ship design and equipment development work. In the same year, the 708th Institute, Jiangnan Shipyard and the Test Base reorganized a design team with combined experience in application, design and production to perform the technical design of the instrumentation ship. It was headed by Xu Fuliang [6079 1381 5328]. In May 1975, after the leadership group reviewed and approved its technical design, construction design of the ocean-going instrumentation ship began at Jiangnan Shipyard under the direction of Xu Mingliang [1776 2494 0081]. The ocean-going instrumentation ship has a long cruising radius and good endurance against wind and waves. It is 191 meters long, 38 meters high and 22 meters wide. Its nine levels are equivalent to a 14-story building. There are over 50 antennas on the deck. Its total displacement with full load is more than 20,000 tons. Its average cruising speed is 18 knots. The ship is equipped with a highly accurate measurement and control system, a multipurpose, multi-network, long-range, all-weather communications system, an advanced navigation and location system and a meteorological system. The electricity consumed on board is equivalent to that of a medium-size city of 300,000 people. This ocean-going instrumentation ship is China's first-generation comprehensive mobile tracking and measurement station. Its development was a highly complex and huge system engineering project and incorporated many new technological accomplishments. In the design, construction equipment development, installation and tuning process, many key technical issues were resolved.

(i) Stability of the vessel and its equipment

In order to maintain the stability of the vessel in heavy seas to ensure accuracy of measurements, the design of the instrumentation ship incorporated three levels of measures. The first level is the stability of the vessel itself. The ship has a pair of retractable stabilizing fins and a super-large single-plate hull. An active rudder and a bow heading device are used together to control drift and bow yawing to make sure that the instrumentation can be stabilized within the range of observation. The second level is to employ a planar coordinate stabilization system on top of the first level to minimize the residual swaying angle of the ship to a fraction of a degree for the instrumentation sitting on the stabilizing platform. The third level is to automatically control the azimuth and pitching angle of the instrumentation to stabilize the accuracy to the second level by measuring the servo systems of onboard equipment such as the radar, telemetry system and dual frequency tachometer and processing the signals by a central computer in order to accomplish the objective of capturing and continuous tracking of targets.

(ii) Minimization of hull distortion and measurement of distortion

Missile tracking imposes very stringent requirements on the instrumentation ship. A small longitudinal distortion of the vessel will introduce a large error in measurement. In order to solve this problem, the 708th Institute took special measures in hull structure design and layout to increase the rigidity of the hull without adding additional weight to the vessel to minimize the distortion in rough water. An onboard optical distortion measuring device developed by the Changchun Institute of Optics and Fine Mechanics was installed to measure the unavoidable residual distortion so that corrections could be made to meet the rigorous requirement for certain precision measurement apparatus such as the laser video theodolite, where distortion is supposed to be maintained to within 1/1000 the length of the ship.

(iii) Vibration damping and noise reduction

There are a large number of precision electronic and optical devices on the instrumentation ship that desire minimal vibration and low noise. The 708th Institute adopted the steam turbine engine manufactured by the Shanghai Turbine Factory, designed a new propeller, and took special structural measures to meet the minimal vibration requirement. In terms of overall layout, the boiler is located in the middle-aft section and the instrumentation is situated in the middle and middle forward section of the ship for maximum separation. They are insulated with double doors filled with foam insulation to reduce noise. The noise levels in the engine room and other compartments were measured and found to meet our specifications.

(iv) Electromagnetic compatibility

The instrumentation ship is equipped with over 50 antennas and more than 1,000 pieces of electronic equipment. Electromagnetic interference becomes a serious problem when there are so many high-power electronic devices working over so many bands on a vessel. The Institute of Instrumentation and Communications of the National Defense Science Commission, the 708th Institute and the Jiangnan Shipyard designed an antenna

zoning plan by taking electromagnetic compatibility measures into consideration. The 704th Institute, the Institute of Cable Research and a cable plant assisted in obtaining coupling interference data, developed a high frequency cable assembly, sorted out cables into separate layers and bundles according to frequency band, and set up special conduits for different cables to suppress coupling. The Changzhou Second Radio Plant developed a better shipboard power supply filter to suppress conductive cable interference. In addition, numerous shielding measures were taken to suppress radiation interference to solve the electromagnetic compatibility problem.

(v) Navigation and positioning

The system engineering department was responsible for the navigation and positioning system. The means for location includes an inertial navigation system developed by Zhang Zongxun [1728 1350 6104] of the 707th Institute, the global, all-weather, high-precision satellite navigation system developed by Ma Yeqin [7456 2814 0530] at the 1020th Institute and the astronomical theodolite developed by Yang Ming [2799 2494] at the 717th Institute. Through the use of a computer, a comprehensive positioning system comprised of these three instruments can use the high-precision positioning data collected by the satellite navigation and astronomical theodolite to calibrate the zero drift of the inertial navigation system accumulated over an extended voyage to improve the location accuracy of the instrumentation ship.

(vi) Long-range all-weather communications

The communications department of the Chief of Staff Command was responsible for the communications system on the instrumentation ship. A comprehensive communications system comprised of a variety of communications means such as long-range, high-power short-wave communications, super-long-wave communications, relay communications, satellite communications and data transmission, frequency and phase-shift telegraph, facsimile, and secure telephone. It is also equipped with a timing system that is based on an atomic clock to ensure the transmission of large amounts of data and information from ship to ship, to shore, and to aircraft under all weather conditions.

(vii) Weather problems

The weather system was the responsibility of the Weather Bureau of the Chief of Staff Command. The vessel is equipped with a comprehensive weather forecast system that is comprised of a weather radar, a sonde, a high-altitude helium balloon launcher, a satellite weather pattern receiver, a radio weather communications device and other conventional meteorological equipment to provide high-altitude weather data over the ocean in a timely manner.

(viii) Salvage and rescue issues

The salvage and rescue system was the responsibility of the navigation safety department of the Navy. The ship is equipped with rescue boats, hydraulic cranes, a helicopter pad and a command tower with the corresponding navigation communications equipment to recover and store the data compartment of the missile, or to rescue astronauts.

(ix) Tracking and measurement

On the basis of the measurement and control plans prepared by the Institute of Instrumentation and Communications of the National Defense Science Commission for the ocean-going instrumentation ship, the vessel is equipped with a measurement and control system that is comprised of a monopulse precision radar developed by the 14th Institute of the 10th Research Academy, a laser video theodolite developed by the Changchun Institute of Optics and Fine Mechanics, a dual-frequency tachometer developed by the 504th Institute, a comprehensive telemetry system developed by the 704th Institute of the Ministry of Aerospace Industry and a central computer system developed by the 15th Institute of the 10th Research Academy and Changsha Institute of Engineering that can handle 1 million computations per second to solve problems associated with tracking, data capture and guidance at sea.

Since 1975, the instrumentation ship has gone through its construction, trial voyage, equipment installation, tuning and calibration stages. Following the order of the Central Special Commission, the Jiangnan Shipyard, the 708th Institute, the Institute of Instrumentation and Communications of the National Defense Science Commission and the instrumentation ship base completed the construction, equipment installation, tuning and shakedown cruise of two instrumentation ships. During this period, under the leadership of Li Qi [2621 1142] of the Shanghai Coordination Group of the National Defense Science Commission, with the cooperation of relevant departments under the jurisdiction of the 6th Ministry of Machine Building and the city of Shanghai, five major tests including technical coordination, gear meshing, performance in sea voyage, calibration and correction were conducted by the Jiangnan Shipyard, 708th Institute, the instrumentation ship base and Naval representatives on site to determine the performance of various measurement devices. During the 1-year test period, it passed 816 special tests and 353 military tests and every item met design specifications. In early 1980, various onboard systems on the instrumentation ship were linked and tested. Its air tracking capability was also calibrated. Finally, after drills along the coast, all systems and equipment were found to work well under the control of the central computer. She was ready for assignment.

This ocean-going instrumentation ship has successfully accomplished numerous missions, including the ICBM test, submarine underwater missile launch tests, communications satellite launch tests and the exploration of

Antarctica. It has contributed considerably to the advancement of science and technology and weapons testing in China.

(2) Ocean-going Survey Ship

The major mission of an ocean-going survey ship is to conduct a survey of a pre-selected test site before an ICBM test or any large scale test takes place. It may also serve as a floating weather station to gather and analyze data and to forecast the weather. It may also be a communications relay ship for the main instrumentation ship. The construction of the ocean-going survey ship was the responsibility of the 6th Ministry of Machine Building, the National Oceanographic Bureau, the Weather Bureau of the Chief of Staff Command and the city of Shanghai. The 708th Institute was in charge of the overall design and the Jiangnan Shipyard was responsible for its construction. The technical design phase was directed by Xu Xueyan and the construction design phase was directed by Lu Zai [4151 0961] of the Jiangnan Shipyard.

The displacement of the ocean-going survey ship is 13,000 tons. It can resist a level-12 storm and can sail anywhere in the world. The onboard weather system is comprised of a weather radar, a rainfall radar, a wind speed radar, a high-altitude helium balloon launcher, a satellite weather pattern receiver and a weather rocket launcher. Its communications system is centered around a 30 kW short-wave system, complete with a variety of communications. The ocean survey system consists of experimental apparatus and laboratory for hydrology, geology, earth magnetic field, gravity, biology, waves and optics. It is also equipped with a hydrophone system and helicopter pad. It is capable of conducting high-altitude weather exploration, scientific ocean survey, underwater communications testing and communications relay. Construction of the ocean-going survey ship began in June 1975 at Jiangnan Shipyard and it was completed in October 1979.

(3) Other Auxiliary Ships

(i) Ocean-going salvage and rescue ship

In order to pick up the data capsule of an ICBM that has splashed down, and to anticipate future needs to rescue submariners and astronauts, it was decided that an ocean-going salvage and rescue ship be built. In order to keep the number of ship models to a minimum and to speed its construction, it essentially has the same design as that of the ocean-going survey ship. The vessel is equipped with a diving rescue vessel, a 56-ton hydraulic crane, a rescue dome, three 25 kg/cm^2 decompression chambers, two large helicopters and a helicopter pad, navigation equipment, and a number of boats. It also has a 1,000-meter deep-water anchor and a 200-meter position-holding anchor to enable the vessel to operate at a fixed position on the sea. The ship was designed and constructed by the same organizations involved in the design and construction of the ocean-going survey ship. Her construction began in 1975 and she was completed and delivered in November 1979.

(ii) Ocean-going supply ship

In order to supply the entire fleet involved in the full-range ICBM test, a 20,000-ton supply ship for both liquid and solid cargo was designed and built by Dalian Shipyard. Her cruising speed is 18.5 knots and she can resist a level-12 storm.

(iii) Rescue and towing ship

In order to ensure that damaged vessels in the ICBM test fleet could be recovered, a 400-ton high-power variable pitch propeller rescue ship was designed and built by Zhonghua Shipyard to provide services such as medical assistance, underwater repair, pumping, supply, and fire fighting at sea. In the ICBM test, it was also responsible for the determination of the splash-down point of the missile.

(iv) Training ship

The "Zhenghe," a 5,500-ton ocean-going training ship built for the Naval Academy, was designed by the 708th Institute and built by the Qiuxin Shipyard. The ship is equipped with a complete set of training equipment to provide training for 108 cadets. In 1988, the "Zhenghe" visited Hawaii.

(v) Large degaussing ship and ocean cable-laying vessel

To degauss large ships and to lay cable, the 708th Institute and honghua Shipyard designed and built a large degaussing ship and a cable-laying ship and completed them in 1973 and 1982, respectively.

(vi) Mother ship for target mine hydrophone tracking system

To meet the requirement in testing naval weaponry at the South China Sea Deep Water Test Site, the 708th Institute designed a mother ship and other auxiliary ships for the target mine and hydrophone tracking system in 1982. The mother ship was constructed by Zhonghua Shipyard with a full displacement of 4,000 tons. It is 112 meters long. It is capable of assembling, testing, maintaining and repairing target mines, hydrophone systems and sonar location systems. It can also be used to launch, deploy, and recover hydrophones, as well as to process measured data on a real-time basis. The auxiliary ship was constructed by the Wuzhou Shipyard. Its maximum displacement is 615 tons and it is 55 meters long. It is used to deploy and recover hydrophones and velocity/depth sensors and accept the data they acquire. It is then transmitted to the mother ship by radio in a coded format. These two vessels were both delivered in 1986.

Section 5. Shipboard Weapon Systems and Equipment

A shipboard weapon system is comprised of shipboard weapons, control devices and measurement equipment.

(1) Underwater Weapons

When the new government was first founded, there were no underwater weapons. The development of underwater weapons was of great concern to the Chinese Communist Party Central, the State Council and the Central Military Commission. Since the late 1950s, a relatively comprehensive technical development, design, production and testing system for underwater weapons has been established. An experienced technical team has been formed to develop a number of underwater weapons of considerable caliber to equip the Navy.

(i) Torpedoes

A torpedo can be launched, controlled, and guided automatically to destroy submarines, surface vessels, and other targets. In the early stage, the Navy was equipped with torpedoes imported from the USSR. In order to produce torpedoes domestically, the 872nd and 874th Torpedo Plants were a part of the 156 major projects supported by the USSR in the 1950s. In April 1958, the Naval Ordnance Department established the Second Naval Research Institute (i.e., the predecessor of the 705th and 710th institutes of the 7th Research Academy). Associate Chief Yang Han [2799 3352] of the Naval Ordnance Department acted as its director. In September 1962, the Navy put Gou Yuanshu [5384 0337 2579], Chief of the Naval Ordnance Department and Associate Bureau Chief of the Fifth Bureau of the 3rd Ministry of Machine Building, in charge of organizing torpedo development and constructing torpedo plants and test sites. In 1965, the Qinghai Lake Torpedo Production and Test Facility was established. In 1966, the 750th deep water torpedo test base and torpedo arming plant were built in Yunnan. In 1968, two more torpedo plants were constructed in Yunnan. The construction of the above plants, institutes and test sites created the necessary condition for the development, production and testing of torpedoes.

In the late 1950s and early 1960s, China began to duplicate Soviet-made thermal powered automatically controlled anti-ship torpedoes for surface ship and submarine use and the jet-propelled anti-ship torpedo used on aircraft. To duplicate these two torpedoes, workers and technical personnel at the 874th, 342nd and 374th Plants and the 705th Institute, with the cooperation of the Northwest Polytechnical University and the Navy, overcame numerous technical hurdles and made repeated breakthroughs. Back then, the 7th Research Academy had just been founded. Director Liu Huaqing [0491 5478 3237] visited the Institute of Torpedo Research numerous times to gain a deeper understanding of the status of the duplication work and to provide direction to this project. He took advantage of the collective team, and gathered funding, equipment, and personnel to overcome various problems and hurdles. In the early 1970s, the design and production model finalization for both torpedoes were completed. They were named the Y-1 and Y-2 torpedo, respectively. This effort laid a preliminary foundation for personnel training and created the environment for development and production.

While we were duplicating the two torpedoes, the 705th Institute began developing an electrically powered acoustically guided anti-submarine torpedo for nuclear submarine use. In November 1965, the National Defense Science Commission held a meeting in Beijing to review the development plan for the electrically powered acoustically guided anti-submarine torpedo. It was named the Y-3. The 705th Institute of the 7th Research Academy was in charge of the overall design of the Y-3. Its chief designer was Dong Lin [5516 3829] and the associate directors were Yang Baosheng [2799 0202 3932] and Jiang Lianfang [3068 6647 2455]. At the end of March 1966, the 705th Institute completed system validation for the Y-3 torpedo. Later, the 7th Research Academy established a number of laboratories to begin the development of the torpedo and its launcher in full scale. As a result of a joint effort of the 712th Institute of the 7th Research Academy, the 1418th Institute of the 4th Ministry of Machine Building and Xinxiang Battery Factory, a high-performance silver/zinc battery was developed in the 1960s to meet the need for the electrically powered acoustically guided anti-submarine torpedo designed by the 705th Institute. The outside casing of the torpedo is a welded aluminum structure designed by Shanghai Jiaotong University. Hudong Shipyard solved the production problem of the torpedo casing. Furthermore, it employed a phase-shift multi-beam guidance system developed primarily by the Institute of Acoustics of the Chinese Academy of Sciences with assistance from the 705th Institute.

The Y-3 torpedo was developed by over 80 production and research organizations, including the 5002 and 5062 plants. This was during the Cultural Revolution. The technical personnel rigorously followed the spirit of the "special open letter" issued by the Central Military Commission on the nuclear submarine project. They eliminated any interference to fight for time to deliver four prototype torpedoes for testing at the 750th underwater test facility in Yunnan in 1969. In 1972, they produced 10 more prototypes to be tested on lakes and at sea. The design was finalized in 1975. In 1983, the Navy conducted numerous production model finalization tests at the Liaonan Torpedo Test Range and solved all the problems encountered in the tests. In 1984, the State Council and the conventional weaponry design finalization committee of the Central Military Commission approved the final design of this torpedo. The successful development of the Y-3 provided the major weapon for our nuclear submarine. It was also our first step toward independent torpedo development.

In the mid-1960s, a passive acoustic anti-ship torpedo was modified by the 874th Plant, Northwestern Polytechnical University and 872 Plant and was named the Y-4A torpedo. The effort was led by Zhang Zhenghe [1728 2973 0735] and Lu Hongxin [7120 4767 2450] as

chief engineers. It was a modification of a Soviet torpedo. The speed of the torpedo was increased by 25 percent and the stability and reliability of its self-guidance system and its fuse were also improved. In February 1984, the final production design of the Y-4 was approved by the State Council and the conventional weaponry design finalization committee of the Central Military Commission.

In the late 1960s, a hybrid active/passive acoustic anti-ship torpedo was developed by Northwestern Polytechnical University in conjunction with the 874th and 872nd Plants. It was named the Y-4B torpedo. Yang Qiming [2799 0796 2429] was the chief designer and Liu Yongzhe [0491 3144 0772], Wang Youyu [3076 2589 0151] and Xie Yiqing [6200 0001 3237] were the associate chief designers. They introduced a non-inertial electric depth detector to replace the mechanical depth controller, employed a new head handling and draining device, and adopted a finned tail to significantly improve its performance. This torpedo was successfully tested numerous times at sea. In February 1984, the State Council and the conventional weaponry design finalization committee of the Central Military Commission approved the final design of the Y-4B. Furthermore, it received a first place national science and technology progress award. This is the first active/passive acoustic anti-ship torpedo independently developed by China.

Since 1980, the 705th Institute has led the development of lightweight active/passive acoustic anti-submarine torpedoes according to models available in other countries. This project was included as a key defense development project in the Seventh 5-Year Plan by the State Council and the Central Military Commission. It is the first-generation anti-submarine torpedo independently developed by China. Its performance is advanced and involves highly complex technology. Its construction requires high-precision machining and involves a large number of organizations. In addition to having the 705th Institute heading development, an on-site torpedo command was established to strengthen the organization and coordination work. Duan Wenbin [3008 2429 2430] was the commander. In order to strengthen the organization and coordination in the development effort, a torpedo design system was established and Huang Zhengyi [7806 2398 0001] of the 705th Institute was the chief designer and Chief Engineer Li Xuan [2621 3551] of the 874 Plant and Chief Engineer Yuan Youmin [0626 1635 3046] of the 872 Plant were the associate chief designers. They were in charge of all technical aspects and overall coordination. With the cooperation of 12 ministry committees and 92 other organizations nationwide, all participating plants and institutions collaborated closely to overcome a series of technical hurdles encountered in the design and construction of the torpedo. A prototype was developed in 1989 and was successfully tested on the lake at the 750th Test Range in Yunnan and on the sea at the Liaonan Test Range, respectively. The results showed that this light-weight combined active/passive acoustic torpedo met all tactical specifications listed in the development request document.

(ii) Torpedo launcher

In 1962, the 705th, 701st and 704th institutes were jointly responsible for the development of a torpedo launcher for the torpedo boat, and the 461st Plant was in charge of its production. It was successfully developed in September 1963 and passed national appraisal in 1964. At the same time frame, the 705th Institute began to design a pneumatic torpedo launcher for submarine use. This is a technically complicated device. It requires that the tube have a high degree of concentricity and linearity and be able to launch without any air bubbles to expose the location of the submarine. After 3 years of hard work, the institute designed over 10,000 parts, solved a series of material and equipment problems, particularly the welded compressed air bottle developed by the Dalian Shipyard, this pneumatic submarine torpedo launcher was successfully developed in 1966.

The development of a torpedo launcher for nuclear submarines began in 1965. The 705th Institute was in charge of its design and the 461st Plant was responsible for its production. Zhang Yian [1728 5065 1344] and Zhang Jian [1728 1017] were the chief designer and associate chief designer, respectively. Upon proof of concept, a balanced hydraulic pressure scheme was adopted so that no bubble would be generated and the submarine could maintain its balance. This device was constructed at the Jiangnan and Dalian shipyards. As a result of the joint effort of the technical staff and workers, technical issues such as titanium alloy processing and molding of corrugated parts were solved. Prototypes were constructed and tested before it became a success. In September 1969, the 461st Plant delivered a complete torpedo launcher to a submarine facility. After a deep-sea launch test, the design was found to be successful.

In the meantime, the torpedo design department and the system validation department also arranged the development of a sonar, a torpedo firing command panel and a navigation device to be integrated with the torpedo and torpedo launcher to form a complete weapon system.

(iii) Mines

Mines are simple, low cost, highly destructive and suitable for use in large quantity. They can lurk in water over an expanded period of time and destroy enemy vessels unexpectedly. China began to develop mines from duplication. In 1957, we started to duplicate Soviet-made mines. The finalized models included a large contact anchored mine, a medium contact anchored mine and a line contact mine. In the 1960s, we successfully developed a sound-activated submerged mine. The tactical and technical specifications of these mines were relatively backward.

In the mid-1960s, specifically in reference to the severe sand sedimentation problem along the coast, the 710th Institute, the 662nd Institute and the 884 Plant jointly developed a sound-activated submerged mine. Moreover, the mine was made to be more resistant against

sweeping and underwater explosion and more effective. From the mid-1960s to the mid-1980s, over 20 types of mines, including a small non-contact bottom mine, an ultrasonic hydraulic bottom mine, an air-dropped large submerged mine, an automatic depth-holding floating mine, a small automatic depth-holding floating mine, a non-contact-trigger anchored mine, a rocket type automatic surfacing mine and a programmed remote control mine, were developed by the 701st Institute, the 848 Plant and the 662 Plant to meet the needs of different surface vessels, submarines, aircraft and manual deployment to create mine fields comprised of sunken, anchored, floating, and automatic tracking mines. In addition, a novel automatic switching technique was employed for the acoustic fuse. A dual magnetic diaphragm receiver was used in the magnetic fuse. Furthermore, major breakthroughs were also made in signal processing of the hydrostatic fuse, piezoelectric transducer and electronic circuitry.

(iv) Counter-mine weapons

China began to copy Soviet-made minesweeping gear in 1958. Designs for a mine-cutting sweeper, an electromagnetic jaw sweeper and an acoustic deep-sea sonic response sweeper were finalized. In 1966, led by the 710th Institute, China began its own independent development of counter-mine weapons. Over the past two decades, a number of counter-mine weapons have been developed. For example, in the early 1970s a Model 312 integrated remote control minesweeper was developed jointly by the East China Sea Fleet, the 710th Institute, 708th Institute and the Zhonghua Shipyard. Because the vessel and its minesweeping equipment are integrated, the vessel is compact, has a shallow draft, and is highly maneuverable. It was highly effective in the Vietnam War. In the 1980s, the relevant units began to develop a new counter-mine system that can put a variety of minesweeping gear on the Type-312 boat.

(v) Depth charges and launchers

China began to copy Soviet-made depth charges in 1959. Beginning in the mid-1970s, it independently developed a number of depth charges. In 1975, the Model 75 rocket depth charge anti-submarine system was developed. Its launcher has 12 barrels. It is capable of automatic angle setting, loading, and tracking and can be launched together or singly. In 1981, the 710th Institute and the 282nd Plant jointly developed the Model 81 depth charge anti-submarine system. The combustion gas is diverted laterally to reduce axial thrust. The tail of the rocket engine was modified to achieve two different ranges to expand the range of attack.

(2) Shipboard Gun Weapon Systems

The shipboard gun is an important part of the weapons systems on surface vessels. The research and development of shipboard guns in China has evolved from manual operation to remote control and from separate control of a single gun to an entire weapon system. In the 1960s and 1970s, in order to meet the urgent need in the field, a number of factories and institutes under the 5th Ministry of Machine Building modified a batch of Soviet-made 57mm guns and copied Soviet-made twin 25mm, 30mm and 37mm ship guns. As a result of this duplication effort, a prototype construction and production line was established and a large number of technical personnel were trained.

To develop independently shipboard weapon systems, the ordnance department of the Navy organized a team to develop a 37mm ship gun in 1958. The 7th Research Academy established the 713rd Institute in April 1963. With the cooperation of other relevant factories and institutes, they successfully developed a variety of shipboard gun weapon systems.

(i) Twin 37mm ship gun system

The shipbuilding engineering department of the China Shipbuilding Corporation was responsible for the development of this ship gun system and Wu Dimin [2976 2769 3046] was the technical person in charge. The 713th Institute was responsible for its design and the principal technical person there was Xie Qun [6200 5028]. The servo system of the gun was designed by the 202nd Institute and produced by the 847th Plant. The twin 37mm gun used the ZPJ-4 electromechanical command panel designed by the 716th Institute and produced by the 454 Plant, the Model 341 gun-laying radar developed by the Second Shanghai Radio Works, and the MZ-2 target display developed by the 559 Plant. After individual components such as the gun, command panel, and radar were finalized, the entire weapon system was tested on land and sea. It was found to perform well and to meet all specifications. In 1984, the design of this twin 37mm shipboard gun was finalized. It is the first small caliber shipboard gun system successfully developed by China.

(ii) Twin 100mm ship gun system

The shipbuilding engineering department was responsible for the development of this twin 100mm shipboard gun system and Liu Guoqing [0491 0948 1987] was the technical person in charge. The 713th Institute was responsible for its design and the 4306 Plant of the Navy and Shanghai Changcheng Elevator Plant were responsible for its production. The major technical people included Xu Jinmiao [1776 6855 8693] and Ying Yanlin [2019 1484 2651]. The system employed the second-generation digital command panel developed by Yu Xichun [0151 1585 4783] of the 716th Institute, the Model 343 gun-laying radar designed by the 720th Institute and produced by the 4110 Plant, and the sighting system comprised of antennas and optical instrumentation designed by the 701st Institute and manufactured by the Hudong Shipyard. In 1982 and 1983, the entire system underwent design finalization tests at the Liaoxi ship gun test range on land and sea. In 1985, the design was officially finalized. This shipboard

gun is more advanced and sophisticated and has better prospects for further development.

(iii) Twin 130mm shipboard gun system

This shipboard gun system is mounted on our first-generation guided missile destroyers. Its development was done by the overall assembly validation department of the 7th Research Academy. The principal technical people were Li Baiyun [2621 4101 0061], Zhu Xibin [2612 6932 2430] and Gu Decai [0657 1795 4101]. In 1968, the 713th Institute began to design the gun and its servo system and the First Heavy Machinery Plant was responsible for its production and the primary technical person was Zhong Jiabing [6988 0857 6333]. Initially, the shipboard gun system used a digital command panel designed and produced by Shen Anjia [3088 1344 1367] of the 308 Plant. Later, the system was improved to use the Model IA multi-processor distributive command panel that displays its major parameters in table form. Furthermore, it was equipped with the 343 radar designed by the 720th Institute. Design finalization test for the twin 130mm shipboard gun was tested on land and sea in 1975 and 1980, respectively, at the Naval Test Base. Later, it was further improved to enhance its performance.

In the 1980s, the twin 37mm ship gun was improved to be a fully automatic, sealed, remote-controlled ship gun system. The twin 130mm gun became microprocessor controlled. In November 1987, its design was finalized by the government and it was named the Model 76 twin 130mm shipboard gun system. In addition, we began to develop anti-missile ship gun systems and new ship gun systems.

(3) Navigation Equipment

Onboard navigation equipment guides the ship along a pre-determined course to ensure safety. It also provides accurate information of the target, including heading, speed, position and attitude, to the weapon system by way of the command and control system.

China began to develop navigation equipment by duplicating Soviet-made conventional equipment such as the sextant. In 1960, the 707th Institute and Jiujiang Instrumentation Plant were established specifically for the development and production of navigation equipment. It began with copying Soviet-made navigation devices and gradually shifted toward independent development to meet different needs. Since the late 1960s, navigation technology has grown in areas such as inertial navigation and combined navigation.

(i) Inertial navigation

Inertial navigation is characterized by an independent navigation system that does not rely upon any external condition. It has excellent stealth capability and high precision and is an ideal navigation system for nuclear submarines and ocean-going instrumentation ships. In September 1965, the 6th Ministry of Machine Building held a meeting to review different proposals for an inertial navigation system. Experts in inertial navigation, including Lu Yuanjiu [7120 0337 0036], reviewed and positively affirmed the development plan for the 915 inertial navigation system prepared by the 707th Institute. After 4 years of work by the 707th Institute, the first prototype 915-1 inertial navigation equipment was constructed. However, there were still several remaining unresolved technical issues. Since 1974, the National Defense Science Commission, the National Defense Office and the lead engineering team for nuclear submarines and ocean-going instrumentation ships have organized a number of experts from different fields led by Ning Guodong [1337 0948 2767] and Zhang Zongxun [1728 1350 3169], to deal with the problems. The effort resulted in the development of the 915-IIA inertial guidance system. After going through stringent laboratory and field testing, more problems were found and resolved. This led to the development of the 915-IIB and IIC inertial guidance systems. They were installed on the ocean-going instrumentation ship and nuclear submarine, respectively. Since the 1980s, under the leadership of Wang Shunting [3076 7311 0080] and Li Zigang [2621 3320 0474], a new inertial guidance system that is more reliable and adaptable to different environments has been developed. Results from field testing and expert appraisal indicate that the accuracy of the inertial guidance system is close to world-class level.

(ii) Astronavigation

An astronavigation system not only has the ability of independent navigation and location on a starlit night but also can dynamically and accurately correct the error accumulated as a result of the continuous operation of an inertial system. It is a necessity for a nuclear submarine or an ocean-going instrumentation ship. The 717th Institute began to develop the high accuracy Model 815 celestial guidance system and the Model 820 astronavigation system in the mid-1970s. The 815 celestial guidance system employs a deck coordinate system. It uses the horizon data provided by the inertial guidance system to track the celestial body using a computer-controlled periscope. The accompanying K-5 computer was developed by the 709th Institute. The atomic clock was developed by the Hubei Institute of Physics. After 3 years of hard work, the 815 starlight navigation system was found to meet all design requirements through system testing and sea testing and then was installed on submarines. The 820 astronavigation system was developed by the 717th Institute under the direction of Yang Ming [2799 2494] in collaboration with the 709th Institute, the 713th Institute and Changchun Institute of Optics and Fine Mechanics. It was completely assembled, tuned and tested at sea in 1978. In 1979, it passed technical appraisal and was installed on the ocean-going instrumentation ship.

(iii) Satellite navigation

In the early 1970s, the 1020th Institute and the Institute of Physics of the Chinese Academy of Sciences organized

a technical team to develop satellite navigation equipment. Since China canceled its own navigation satellite program, a decision was made to use the signal from the NNSS transit satellite system of the United States to develop shipboard receivers. In 1979, Ma Yeqin [7456 0673 0530], et al. of the 1020th Institute developed such a receiver. It was installed on our ocean-going instrumentation and survey ships and completed numerous precision location measurements. In the mid-1980s, the 1020th Institute, the Department of Systems Engineering, the 750 Plant and the 765 Plant successfully developed a series of improved shipboard receivers, the WD-II and WYD-I satellite navigation systems, the WYD-II/Omega combination navigation system and a small satellite navigation system. A new territory in satellite navigation was created to serve as a foundation for future development of satellite navigation in China.

(iv) Combination navigation

Computers and software have been used in every field since the 1970s. Ship navigation systems are moving toward integrated combination systems. A combination navigation system was developed by the Department of Systems Engineering of the China Shipbuilding Industry Corporation under the direction of Luan Yongnian [2940 3057 1628]. They combined eight pieces of equipment used in inertial navigation, astronavigation, and satellite navigation to create a single computer controlled navigation system to provide accurate navigation and location information. Harbin Shipbuilding Institute, the 707th Institute and the Ship Systems Engineering Department also developed a variety of combination navigation systems for medium and large vessels such as the "Zhenghe" training ship, guided missile frigates, and destroyers.

In the past four decades, the development of navigation equipment in China has progressed from duplication to independent development. It has met our preliminary goal of serialization, generalization and automation and is marching toward high accuracy and reliability.

(4) Sonar Equipment

Sonar equipment is used for underwater detection, location, tracking, and navigation. It is the underwater observation equipment for shipboard weapon systems. In 1956, sonar equipment was listed as a key issue in the national 12-year plan for science and technology. It has run through the course of three stages, i.e., duplication, independent development, and application of new technology.

(i) Submarine Sonar Equipment

China built a sonar equipment factory in the late 1950s. In the early 1960s, it began to duplicate sonar equipment for medium size torpedo submarines. In the mid-1960s, the 706th Institute began to develop the SQZ-3I and SQZ-3II general purpose sonar and TS-6 mine detecting sonar for submarine use. These devices were installed on nuclear submarines in 1970. In 1975, they passed design finalization and went into production. During this period, the Institute of Acoustics of the Chinese Academy of Sciences, Jiangning Machinery Plant, and the Shanghai 22nd Radio Plant also developed the SQW-3 sound-speed and sound-ray tracking plotter and the SQC-I reconnaissance sonar for nuclear submarines. The Dongfeng Machinery Plant and the Institute of Acoustics of the Chinese Academy of Sciences developed the SQZ-A general purpose sonar for conventionally powered submarines. Under close cooperation between the Navy and the Chinese Academy of Sciences and various industrial organizations, the 706th Institute completed the development of a variety of sonar equipment within a short period of time.

(ii) Surface Vessel Sonar Equipment

From the mid-1960s to the early 1980s, the 706th Institute, Jiangning Machinery Plant and Jiangxin Machinery Plant successfully developed the SJD-2, SJD-3, SJD-4 and SJD-5 shipboard echo sonar and the SJC-1B reconnaissance sonar for various surface vessels to complete missions such as range finding and reconnaissance.

(iii) Communications Sonar

In 1965, Harbin Military Engineering Institute began to develop the SQX-3 submarine communications sonar and SJX-4 surface vessel communications sonar. Later, the responsibility was transferred to the 706th Institute. The project was completed in 1982. These two sonars use a mosaic cylindrical transducer. It has a high transmission efficiency and reception sensitivity. It employs a lightweight glass truss and has excellent sound penetration. It has a large range and can identify friend from foe. When used on conventional submarines and guided missile frigates, it guarantees communications between submarine and surface ship. In order to solve the communications problem between submarine and surface ships, the Jiangning Machinery Plant developed the SJX-2 communications sonar. It passed production design finalization in September 1974. The Jiangxin Machinery Plant also developed the SQX-1A and SQX-1B small dedicated communications sonar to be installed on deep-dive submarine rescue vessels and deep-dive vehicles.

(iv) Sonar Warfare Equipment

These are defensive devices that provide protection and confuse the enemy. In addition to the SQK-1 smoke bomb duplicated by the 718th Institute in the mid-1960s, other sonar warfare devices developed include the SQK-3 low frequency and SQK-3 high frequency interference device produced by the 718th Institute, 710th Institute and Shanghai 22nd Radio Plant. Design finalization and equipment deployment of these devices were done in 1987. Besides, the 750th Test Range and Jiangxin Machinery Plant developed the SQK-5 self-propelled and the SJK-6 towed decoys.

(v) Special Sonar Equipment

In addition to shipboard and submarine sonar equipment, China also developed a variety of special purpose sonar equipment, such as the SKD-41 aerially deployed sonar developed by the Northwestern Polytechnical University and the 706th Institute, the SKD-42A aerially deployed sonar developed by the 706th Institute, and the aerially deployed sonar developed by Northwestern Polytechnical University and the 872nd Plant. These sonars were found to perform well and passed technical appraisal and design finalization. Design finalization of the SKF-1 passive all-directional sonar buoy, which was jointly developed by the 706th Institute, 972nd Plant, Jiangning Machinery Plant and 712nd Plant, was approved in 1967. Design finalization of the HF-2 aerially deployed non-directional sonar buoy, developed by the 872nd Plant, was passed in 1972. They are installed on seaplanes. Furthermore, certain organizations developed a land-based general purpose sonar, a long baseline location system, a torpedo sonar system and special sonar equipment for the test base.

In the 1980s, digital and microprocessor technology was introduced to sonar equipment in China. Emphasis was placed on design reliability. Major performance characteristics and capabilities are approaching those of similar foreign products in the early 1980s.

Section 6. Hydrodynamics Research and Experiments

Hydrodynamics is the science that studies the relative motion between an object and a fluid, including the state of the object and that of the fluid and their mutual interaction. It is also the major basic science for military ship technology. Hydrodynamic experiments can predict the hydrodynamic behavior of a vessel in a variety of sea conditions so that modifications can be made to continuously improve the ship. It can provide the data needed to control the underwater trajectory and surfacing process of a missile launched under water. It also can create conditions necessary to develop a "quiet" submarine and to improve the performance of sonars and guided torpedoes.

(1) Construction of Hydrodynamics Research Organizations and Experimental Facilities

Prior to 1949, there was no special research organization or experimental facility to study hydrodynamics. After the new government was founded, the Bureau of Shipbuilding Industry of the Ministry of Heavy Industry began to establish research organizations and experimental facilities for hydrodynamics.

(i) Creating an organization to conduct research on hydrodynamics

In 1950, the Bureau of Shipbuilding Industry decided to build a ship model test basin based on expert recommendation. In 1954, a small cantilever ship model test basin (major dimensions are 70 x 5 x 2.5 m, speed 0.1-5 m/sec) designed by Yan Jiaji [7346 1367 7535] and Ge Zhengyi [5514 2973 5030] to study ship fluid dynamics was constructed and put in operation in Shanghai. At the same time, the Institute of Ship Model Testing was created to perform the necessary tests. In 1965, the Institute of Ship Model Testing was renamed the Institute of Shipbuilding and began to investigate a plan for a large towing basin. In 1957, the Institute of Ship Science was established by the First Machine Building Ministry and Transportation Ministry. In the late 1950s, the Institute of Ship Science began to build a hydrodynamics research base in Wuxi. In this period, test basins and facilities were constructed at Shanghai Jiaotong University and Dalian Naval Machinery School. The First Naval Research Institute also built a deep ship model test basin. After the Seventh Research Academy was established in 1961, the 702nd Institute was established to study ship performance on the basis of some of the researchers at the Institute of Ship Science and the Ship Principle Laboratory of the First Naval Research Institute. Between 1961 and 1965, more than 300 college and professional school graduates in shipbuilding, electronics and mechanics were assigned to the 702nd Institute. It held high level classes on hydrodynamics to train key employees to bring the technical team up to speed. A foundation for the study of hydrodynamics was established. The major research effort was switched to the study of hydrodynamics associated with military vessels.

(ii) Construction of experimental facilities for hydrodynamics

In order to meet the need in the development of our first-generation military vessels, the State Planning Commission officially approved the construction of a large-scale hydrodynamics experimental facility in Wuxi in 1963. It was listed as a key national construction project. As a result of the effort of the 702nd Institute and other relevant organizations, China's largest deep-water ship model towing basin designed by Liu Xin [0491 7451], et al. of the 702nd Institute was completed and put into operation in 1965. By the end of the 1960s, the underwater explosion basin, large wave basin and jointed-arm basin were designed by the 702nd Institute and put into operation.

The deep-water ship model towing test basin is used to study the overall performance of ships. The basin is 474 m long, 7 m deep and 14 m wide in the middle and 7.5 m wide in other areas. A man-carrying frame is used. There are two tractors, one primarily for surface vessel models and the other for submarine models. There is a moving plate wave maker at the end of the basin. It can be used to measure the drag and cruising speed of a surface ship, submarine, or torpedo to facilitate model and profile selection.

The underwater explosion test basin is used to determine the capability of the underwater structure of a vessel to withstand an underwater explosion. The basin has a diameter of 85 m and a maximum depth of 16 m. It is equipped with a floating test platform. The basin and the measurement system in the laboratory are connected by

a 60 channel coaxial cable. The test equipment includes a 20 MHz transient recorder and a computer controlled magnetic tape deck and a high-speed analysis system. This facility was at world class level at the time it was built.

The wave basin (environment simulation basin) is used to test the seakeeping quality of a surface vessel. It provides the data needed for ship design selection. The basin is 69 m long, 46 m wide and 4 m deep. It is equipped with a rotating bridge with a maximum angle of rotation of 45 degrees. A trailer is suspended under the bridge, which has a maximum speed of 4 m/sec. Air wave makers are installed on two adjacent sides of the basins, eight units along the short side and 13 units along the long side, to generate regular and irregular waves as desired.

The jointed-arm basin is used to determine the hydrodynamic characteristics of a ship model when it is turning on the surface or under water. The circular basin has a diameter of 48 m and a depth of 4.5 m. The maximum rotating speed of the jointed arm is 1 radian/sec. At the maximum radius, it corresponds to a linear velocity of 20 m/sec.

From the early 1970s to the 1980s, the 702nd Institute designed and constructed a low speed wind tunnel, a large cavitation cylinder, a structure impact pool, a water/air basin and a variable pressure basin.

The low-speed wind tunnel is used to verify the maneuverability of underwater vessels in a moving fluid and to observe the air drag associated with a surface ship. The tunnel has an octagonal cross-section with a 3 m diameter. The experimental section is 8.5 m long. The maximum wind speed is 93 m/sec.

The large cavitation cylinder is used to study the propulsive force, torque, and cavitation characteristics of propellers in order to select an optimal scheme. The cylinder is 0.8 x 3.2 m in dimension with a minimum cavitation factor of 0.15, maximum water speed of 20 m/sec, maximum propeller rotation speed of 4,500 rpm, maximum propulsive force of 800 kg and maximum equivalent torque of 50 kg.

The structure impact basin is used to perform impact tests on ship structures. The basin is 15 m long, 5 m wide and 5 m deep. The maximum impact acceleration is 7 m/sec^2. The basin is equipped with a hydraulically controlled medium strength impact tester to evaluate the effect of impact on shipboard equipment ranging from 200 kg to 2 tons. It also has a 4 m free fall impact machine to perform single pulse impact experiments on small models ranging from 30 g to 100 kg and a fast Fourier analyzer that can perform mode recognition of a highly complex structure.

The water/air basin is used to study the motion of an object between air and water to provide background information required for the understanding of the entrance into the water of a submarine-fired missile or torpedo. China designed and developed two water/air basins. The one completed in the late 1970s is 25 x 5.5 x 9.5 in dimension and has a maximum speed of 3 m/sec and an 18 x 10 m camera window. The large basin completed in the mid-1980s is 25 x 6.5 x 12.5 m.

The variable pressure basin is used to study the drag and propulsion of a ship model under cavitation and to determine the hydrodynamics of various weapons in simulated sea battle situations. The major dimensions of the basin are 150 x 7 x 4.5 m, the maximum vacuum is 1/20 atm, and the highest trailer speed is 13 m/sec.

During this period, ship model testing basins were also constructed at the Zhongshan University, Shanghai Institute of Shipping and Transportation of the Ministry of Transportation, Wuhan College of Waterway Shipping Engineering, Dalian Institute of Engineering, Tianjin University, Nanjing Institute of Engineering, Shanghai Jiaotong University, Harbin Shipbuilding Engineering Institute and the 708th Institute. Northwestern Polytechnical University and the 605th Institute of the Ministry of Aerospace Industry also built test facilities to study the hydrodynamics of torpedoes and seaplanes. The high speed water cylinder constructed by Northwestern Polytechnical University is 11.5 x 11.6 m in size. It has a working section that is 400 mm in diameter and 2,000 mm in length. The water speed can be varied from 0-18 m/sec and the pressure ranges from 0.2-3 absolute atm. Under the direction of Chief Designer Huang Jingquan [7806 2529 3123], the cylinder was completed in September 1983. In November of the same year, its fine tuning was finished under the direction of the head of the water cylinder laboratory at the California Institute of Technology. It has an excellent flow field and acoustic property in the working section. In addition to routine studies such as cavitation, fluid dynamics, flow field visualization and analysis, it is capable of measuring and studying fluid dynamic noise of a body such as a torpedo.

These test facilities played a critical role in the development of military vessels, naval weapons and shipbuilding technology.

(iii) Developing experimental hydrodynamics techniques

Testing techniques are an important way to evaluate the level of experimental research in shipbuilding. During the course of constructing its experimental facilities in hydrodynamics, China also stressed the improvement and development of testing techniques. In the 1950s, steel wire or connecting rod navigation instruments were used in experiments. In the 1960s, electromechanical or electrical test devices were developed to overcome the shortcomings of mechanical devices to improve accuracy and efficiency. In the late 1970s, the 702nd Institute employed computer and digital control technology to develop a digital irregular wave maker and other digital

instruments. In the 1980s, test apparatus in hydrodynamics research entered an era of automatic servo control and non-contact telemetry mode. In servo control and data processing, a microcomputer is integrated with the test apparatus to form an automated test system. Some towing basins can perform fully automated test and real time data processing on drag, sailing, and open-water experiments to improve efficiency. This signified that China had reached a new plateau in hydrodynamics testing techniques. Unique test instruments and techniques include:

Inclined flow cylinder to measure work done. This has an adjustment mechanism that is easy to operate. It is compact and has a small strain gauge transducer that is highly accurate. It may be used to test inclined flow of a propeller model in a cavitation cylinder. By coordinating with the upstream axis, it can be used to test propellers. With a 50 percent propeller force gauge, it can be used to adjust propeller and to study its dynamic characteristics to further expand the usefulness of the cylinder.

Digital flash camera system. This is fully digitally controlled and can be used to observe and take pictures of cavitation on any propeller blade. It may also be used to observe and photograph the motion of a vibrating or rotating object.

Variable torque cross-rocker. This is an effective means to study non-linear cross-rocking. It can expand the test range of a ship model to a maximum amplitude of 30 degrees in order to obtain its hydrodynamic coefficient.

2.6-meter camera/periscope. This is a special periscope that is directly installed in the towing basin to monitor the flow pattern around the ship model beneath the water surface and to observe other physical phenomena. It can take single-shot pictures at a fixed point or be used in continuous dynamic observation and photography.

Regeneration of inhomogenous cavitation flow field. An inhomogenous flow field is produced in a large cavitation cylinder with a skin-mounted screen to simulate flow field distribution at the stern. It offers a new way to study the pulsating pressure, activation force and corrosion resistance of the propeller. Its experimental accuracy is close to that of a comparable cavitation cavity abroad.

The development of new hydrodynamics test equipment and the improvement of the measurement standard indicates that China has made substantial progress to improve its testing capability in hydrodynamics. It plays a critical role in the development of military vessels and naval weaponry.

(2) The Role of Hydrodynamics Research in the Development of Naval Weapon Systems and Equipment

(i) Effect on submarine development

The contribution of hydrodynamics research is most obvious in submarine development. In the mid-1960s, China decided to develop nuclear powered submarines. Under the direction of Zhang Jingcheng [1728 2529 6134], hydrodynamics research on nuclear submarines was initiated at the 720nd and 719th institutes. It had a major effect on ensuring its development progress and quality.

Selection of a tear drop profile. In the mid-1960s, research personnel and total assembly designers conducted over 30 experiments on a variety of hydrodynamic models. By means of theoretical calculation and motion simulation, basic patterns governing various fluid dynamic parameters, motion characteristics and quickness of a tear drop shaped submarine were gradually understood. Methods for theoretical calculation and analysis were developed to meet the design needs.

Overall performance test for model selection. In coordination with total assembly design, the hydrodynamics research department conducted a variety of tests to compare a number of design schemes for torpedo and guided missile nuclear submarines in the model selection process. In addition, a variety of towing tests under different cruising conditions, dimension effect tests, propeller cavitation cylinder tests, and near surface effect tests have been performed to provide the necessary data for ship model selection and design verification.

Seakeeping quality experiments on models. Since the late 1960s, the experimental hydrodynamics research department conducted numerous surface and near surface seakeeping quality tests on models to predict the performance of submarines. In 1975, a special program was written based on theoretical calculation to provide data for underwater launching of missiles from a submarine.

Maneuverability experiments. During the technical design stage, the hydrodynamics research department conducted a number of mobility and maneuverability tests for the submarine to determine factors such as the geometric shape of the stabilizer fin and rudder, its major parameters, the hull layout, the rudder engine power, and the geometric position and efficiency of the rudder axis. In order to measure the rotation derivatives of the submarine, a wind tunnel forced vibration device, a phase analyzer and electric force balances were developed. The forced vibration device and a jointed-arm basin were used to measure the rotation derivative of the submarine. As a result, an experimental method and a program were established to measure the rotation derivatives of an underwater object. Wan Tingdeng [8001 1694 6989] et al. calculated the imaginary mass coefficients for the six degrees of freedom of a torpedo nuclear submarine using a binary slice method. Computer simulation was used to calculate the maneuverability of the submarine on the vertical and horizontal plane.

Study of explosion resistance and vibration characteristics. In order to determine the safety radius of the

pressure-resistant hull, underwater explosion experiments were conducted at the reactor cabin, main engine room, and missile compartment. In order to measure the intrinsic frequency of the shock-reduction systems associated with the main and auxiliary engines, the vibration characteristics of the hull were studied experimentally. A method was developed to test and calculate the overall vibration of a submarine. Recommendations to improve the method were also presented. The vibration of the astronavigation system onboard a nuclear submarine was calculated to ensure that it operates normally at the cruising speed of the submarine. The study of submarine fluid dynamics not only provided important data for its development but also expanded the field of experimental research, raised the level of theoretical analysis, and educated a large number of technical people. It also promoted advances in the study of hydrodynamics associated with ships in China.

(ii) Effect on surface vessel development

Anti-submarine frigate. Because an anti-submarine frigate has four aft propellers, this presents a number of problems in the design of the aft profile. To this end, the design department prepared more than 10 designs of various lengths and profiles. Satisfactory results were obtained from drag and other hydrodynamic tests in experimental basins. Finally, a round design was adopted. After the first prototype was constructed, additional improvements were made on the aft profile and accessory layout based on tests done on the actual vessel. The propeller load was adjusted to raise the cruising speed of ships built later by 0.5 knot. It created a new approach to the study and design of the hydrodynamics of surface vessels.

Guided missile destroyer. The development of the first-generation guided missile destroyer began in 1965. It has a high tonnage and high cruising speed. A round bow design was used for the first time. A great deal of hydrodynamics research and ship model experiments were conducted in order to predict the quickness and seakeeping quality of the vessel and to select the optimal profile and major dimensions. Actual ship test results showed that the ship profile not only ensures high speed but also excellent seakeeping quality. It is the successful model. In 1975, in order to meet requirements in advanced research on a new destroyer, a series of studies was conducted on the quickness of destroyers. By way of experimentation, dynamic drag and effective power as a function of length to width ratio and rectangular coefficient and effect of location and size of the spherical bow on its drag were obtained. Methods were developed to calculate the stability of surface vessels, including destroyers, under the combined effect of wind and waves and wave impact when a vessel sails against the wind.

Ocean-going instrumentation fleet. On the basis of special requirements of the ocean-going instrumentation fleet, comprehensive experiments were done on all major ship models to determine their hydrodynamic characteristics. Furthermore, certain key problems associated with these vessels were resolved. For instance, the load of an ocean-going surveying ship is highly variable and is concentrated in the middle of the vessel. It has a major impact on the bending resistance of its hull in heavy seas and on the swaying period of the ship, which directly affect the measurements. The situation was clarified by way of hydrodynamics experiment. The problem was resolved by adopting a series of measures in the overall design of the vessel. In addition, excellent results were obtained from a winch cable tension experiment for the ocean-going supply ship.

(iii) Impact on weapon development

In the 1960s, research on the hydrodynamics and maneuverability of torpedo was initiated at the 705th Institute and Northwestern Polytechnical University. In the late 1960s, in coordination with the effort to develop an electrically powered, sound-guided anti-submarine torpedo, the 702nd Institute conducted a study on a special torpedo engine. A theoretical method to calculate circulation near a rotating propeller was presented. It provided the data necessary for the development of a low-noise propeller. Furthermore, experimental studies on jet propulsion and low-noise torpedo head profiles were also performed. Since the 1980s, studies have been done on water impact hydrodynamics, cavitation development pattern, and hydroballistic with cavitation associated with torpedoes dropped from aircraft. Exploratory work was done on water impact buffering and on submersion stability technology.

To assist the development of guided missile nuclear powered submarine, Cheng Guanyi [4453 6306 0001], et al. at the 702nd Institute initiated a series of studies on underwater missile ignition, missile surfacing process and missile attitude maintenance since the early 1970s. They launched more than 3,000 underwater vertical launches of missile models and successfully predicted a number of performance parameters such as attitude and scatter which are in good agreement with actual test results. In addition, schemes to modify the missile profile and to expand the tail were presented to improve its hydrodynamics upon leaving the water.

(iv) Strengthening technology reserve in hydrodynamics research

Study of cavitation mechanism. The 702nd Institute did a great deal of work on the effect of flow state, air content and propeller roughness upon the inception, growth, and disappearance of cavitation. Theoretically, a linear and a non-linear solution for circulating flow were developed. This provides a basis for cavitation-free, low-cavitation and cavitation-resistant design to minimize noise, drag, corrosion and vibration.

Study of ship noise. Hydrodynamics research made it possible to reduce ship noise and to develop long-range sonar. The 702nd Institute, with the cooperation of the 725th Institute, the Institute of Acoustics of the Chinese Academy of Sciences, and Tianjin Institute of Rubber Research, conducted experimental research to reduce

submarine propeller noise by using a sound-absorbing material in its inner cavity. This reduced the effect of engine noise on its own sonar. In addition, studies on hydrodynamic noise and noise reduction mechanisms and the boundary layer of a moving object in water were also initiated in preparation for the development of low-noise, high performance, "quiet" ships and weapons.

Improving combat capability in different sea conditions. In the 1960s, Liu Chuxue [0491 2806 1331] at the 702nd Institute began to study the seakeeping quality of guided missile destroyers and other vessels. It began with predicting the behavior of the ship under regular and irregular wave conditions. It eventually resulted in the development of a ship design optimization method that balances both seakeeping quality and quickness requirements. It allows us to use a computer to directly select the optimal ship profile based on the tactical requirements. In addition, based on slice theory, a three-dimensional hydrodynamics method to calculate ship motion was developed through theoretical and experimental studies on the seakeeping qualities of hydrofoils, catamarans, shallow-draught vessels and engineering ships. These experimental results will further improve the combat capabilities of our ships.

Study on ship propellers. Since the late 1970s, in the process of improving the propeller of conventional submarines, the hydrodynamics research department designed a new propeller using a theoretical method based on the lift line and lift surface of a circulating flow. The underwater speed of the submarine was raised by 1 knot, propeller cavitation ceased and noise was substantially reduced. In addition, through a series of cavitation cylinder tests for various propellers, researchers established the experimental patterns for all the propellers used in China. Studies on energy-conserving propellers and jet propulsion were initiated. A perfected design was established for water jet propulsion. On the basis of theoretical research on propeller lift line and lift surface and propeller cavitation mechanisms, a comprehensive design method and experimental procedure have been established. This has an important effect on the design of a high-efficiency propeller.

After nearly four decades of construction and development, China has created a relatively complete system for hydrodynamics research that is centered around the experimental facilities at Wuxi Hydrodynamics Research Center. It includes higher learning institutions and related industrial organizations. We have a high-level technical team that is well trained and experienced. It plays a critical role in the development of naval vessels, naval weapons and equipment and shipbuilding.

Since the founding of the our new government, China has designed and built more than 6,000 military vessels and developed a variety of weapons and equipment. Their performance levels are continuously improving. Some military vessels and certain technological fields are approaching world-leader level. Nevertheless, compared to other countries, there is a substantial gap in weapons and electronics. China will continue to strengthen its basic and applied research on shipbuilding technology. It will concentrate on key technologies involving air defense, anti-submarine warfare, early warning systems, and anti-missile warfare. A new generation of ships and weapons will be developed to contribute to the defense of the long coastline of China.

Chapter XXI. Testing of Conventional Naval Weapon Systems and Equipment

The tactical and technical characteristics of conventional naval weapons and equipment must be evaluated under near-combat conditions. Except for a few that can be directly tested by naval forces in the field, most weapons and equipment must undergo tests for development, verification, and design finalization at a base that is equipped with special facilities and instrumentation. To this end, the Navy built a variety of test sites for conventional weapons while it constructed the guided missile test range to create a comprehensive test base for naval weapons and equipment.

Section 1. Construction of Naval Conventional Weapon Systems and Equipment Test Ranges

Based on the need to build up naval weapons and equipment, the Central Military Commission decided to establish an organization to oversee the testing of naval conventional weapons and equipment in January 1964. In December 1965, with the approval of the Chief of Staff Command, the conventional weapons testing department of the naval test range was created to plan the construction of test ranges for underwater weapons, shipboard guns, and guidance systems. Huang Jingwen [7806 2529 2429] was the department head and Wang Jiahe [3769 1367 0735] was the political advisor.

Because various naval weapons have different test conditions and requirements, it was decided to build a shallow-water weapons test range in Liaonan and a shipboard gun test range and a guidance equipment test laboratory in Liaoxi. In July 1966, the National Defense Science Commission, the Navy, and the Sixth Ministry of Machine Building jointly reviewed the construction plan for the test ranges. The Navy then began to carry the construction work. In the 1970s and 1980s, in response to advances in conventional weapons and equipment, a deep-water test range and an electronic warfare test site were built in the South China Sea with the approval of the State Council and the Central Military Commission to conduct tests on deep-sea weapons and electronic warfare equipment.

(1) Construction of Shallow-Sea Underwater Weaponry Test Range

Testing of underwater weaponry primarily depends upon sonar measurement because the tests are affected by water propagation characteristics. It is more difficult and involves complex technology. After survey and

validation work, the Navy chose to build China's first shallow-sea underwater weaponry test range in Liaonan (Liaonan Test Range). Song Peihua [1345 1014 5478] was the director and Qi Qingshan [7871 3237 1472] was the deputy political advisor. They were responsible for the construction of the test range and for the organization of underwater tests of torpedoes, mines, and depth charges.

(i) Construction of torpedo test facilities

The key issues in organizing torpedo testing are the construction of test facilities and development of accurate and reliable instruments. In the mid- and late 1960s, before the Liaonan Test Range was completed, thermally powered automatically controlled anti-ship torpedoes were tested along the coast in Qingdao, Lushun, and Zhoushan to meet our urgent needs. These tests required the mobilization of our ships over long periods of time. Moreover, measurements were made using outdated techniques. Very little data was gathered with poor accuracy. It was very difficult to provide a scientific evaluation of torpedo performance to meet the objectives of the tests. It was concluded that a fixed test launch facility with special instrumentation had to be constructed before additional torpedo tests could be conducted. As a result of the hard work done by the naval test range conventional weaponry testing department, the first sea-based fixed torpedo launch facility in China was completed in 1972. The facility is 20 m long, 18 m wide and 18.7 m high. The portion above the waterline is 7.2 m high and has three stories. It is equipped with a surface ship and submarine torpedo launch systems to simulate the firing of anti-ship torpedoes from surface ships and submarines, respectively. The facility is connected to a pier by a 240 m steel beam bridge which is used to transport torpedoes. Multiple torpedoes tests can be conducted daily. This not only substantially reduced the number of ships required but also more importantly created an initial condition to conduct controlled torpedo testing. It accurately maintains the bearing and attitude of the torpedo and eliminates any incidental factors that are associated with the motion of the ship to more reliably determine the performance of the torpedo.

In order to evaluate the performance of a self-guided torpedo, a standard acoustic target is needed. In 1972, Meng Qingji [1322 1987 3444] of the Liaonan Test Range proposed a preliminary simulated noise source. It was further developed by the Nanjing Institute of Engineering. In 1982, the Institute of Acoustics of the Chinese Academy of Sciences developed a torpedo automatic noise tracking correlator to measure its underwater trajectory. During this period, Liaonan Test Range and Qiqihar Second Northern Radio Plant developed an internal magnetic recorder for torpedoes. These devices worked well in torpedo testing.

(ii) Construction of torpedo test facility

In the early years of the Liaonan Test Range torpedo testing was crude. Its technical staff, on one hand, managed to complete their assignments with what they had. At the same time, they were actively engaged in the development of test equipment. In 1970, Pan Shangbin [3382 1424 2430] of the Liaonan Test Range presented a fuse testing scheme. It was manufactured by the 721st Plant. The main component of this device is installed on a ship and the torpedo is equipped a sonar transponder. In 1980, Pan Shangbin designed a telemetry unit that transmitted the fuse signal via radio, instead of sonar. It was successfully developed by the 884th Plant. It satisfied the requirements of simultaneous multiple torpedo testing at high cruising speeds. Determination of the power of an underwater explosion is critical to the understanding of the charge loading to produce an even larger destructive effect. The Liaonan Test Range cooperated with the 702nd Institute and the Institute of Mechanics of the Chinese Academy of Sciences to develop a pressure measurement device for underwater explosion in the mid-1970s. It preliminarily solved the problem associated measuring underwater explosion produced with torpedoes loaded with a large amount of explosives. In the 1980s, Zhao Hongchun [6392 3163 2504], Li Changqiong [2621 2490 8825] and Zhao Lin [6392 3829] of the Liaonan Test Range and Zhang Jincheng [1728 6855 1004] and Lu Zhongli [4151 1813 4409] of the Institute of Mechanics of the Chinese Academy of Sciences jointly developed a digital remote explosion pressure gauge to improve the reliability of the equipment. In the mid-1980s, under the direction of Associate Director Cheng Yankang [4453 1693 1660] of the Institute of Mine Research, a microcomputer-based remote underwater explosion pressure measurement system was successfully developed by using two-stage computer control, multiple redundancy technology and modular IC structure to create a new generation of equipment for underwater explosion measurement.

(iii) Construction of depth charge test facility

The most important tactical and technical specification to evaluate during the testing of a depth charge is its sinking speed. Liaonan Test Range worked with Beijing University and the 612th Plant to develop an instrument to measure the underwater trajectory of a rocket-propelled depth charge. In conjunction with the fixed-depth sounder/speedometer developed by the depth charge laboratory of the Liaonan Test Range, problems associated with the measurement of sinking speed were resolved.

After over two decades of construction, Liaonan Test Range has completed more than 100 test assignments on torpedoes, mines, and depth charges. The testing of underwater weaponry is becoming standardized.

(2) Construction of Ship Gun Test Range

Shipboard guns and land-based guns have a great deal in common. In order to make full use of the test range for land-based guns, usually testing for individual gun and charge performance is done at the Baicheng Conventional Weaponry Test Range. However, land testing

cannot reflect the actual field conditions such as wave interference, multiple path effect and environmental factors such as salt, fog, and mildew that the weapon system will experience when it is installed on board a ship. It is also hard to effectively simulate the characteristics of an enemy "target" approaching by sea. Therefore, a special sea test range was built in Liaoxi. It is responsible for the testing of ship guns, command panels, radars, and optical instruments. Key facilities constructed for the ship gun test range include the coastal test front, testing shop and data processing and instrumentation room. The coastal testing front is 100 m offshore and 50 m below sea level. The target approaches from the ocean to reflect true sea background conditions such as wave interference and multiple path effect.

Since the mid-1960s, on the basis of the needs of different testing assignments, it has been equipped with optical measurement instruments, high accuracy radar, various gun targets, ship targets, air targets, parachute targets and towed targets. It has completed the design finalization for more than 20 models of weaponry in over 50 projects.

(3) Establishment of Navigational Equipment Test Institution

In the mid-1960s, the National Defense Science Commission and the Navy decided to establish a navigational equipment test institute in the naval test range conventional weaponry testing department. It is primarily responsible for the testing of compasses, range-detectors, depth-detectors, azimuth levels, inertial navigation systems, astronavigation systems and radio navigation systems. For over 20 years, with increasing test loads on navigational equipment and more demanding testing requirements, the institute has gradually installed a variety of instruments to acquire and store data in order to perform equipment appraisal and design-finalization tests. The degree of automation in sea testing is improved. A set of equipment calibration procedures was established. A test protocol for design finalization was formulated. It has performed over 40 assignments to test navigational equipment.

(4) Establishment of Follow-Up Deep-Water Test Range

In the mid-1960s, during the planning stage of the shallow sea Liaonan Test Range, the construction of a deep water test range was considered to perform testing on deep water torpedoes, explosives, depth charges, sonar and deep-water behavior of submarines. In 1973, after the Navy completed a preliminary survey, with the approval of the State Council and the Central Military Commission, a follow-up deep-water test range was being built in the South China Sea. Qian Yueren [6929 6390 0117] was the commander and Hu Riheng [5170 2480 5899] was the political advisor. To choose an ideal deep-water region, the Naval Test Base organized two survey trips in 1973 and 1977. They recommended two test ranges, southeast of Hainan Island and near the Xisha Islands. Their recommendation was approved. Soon afterward, construction of the deep-water test range and sea test facilities began.

Deep-water weapons testing is more demanding as far as test facilities and conditions are concerned. The deep-water test range has four fully-functional mother ships and auxiliary vessels that are equipped with advanced testing and operating equipment such as target mines, sonar tracking systems, sonar location systems, radio location systems, manned diving vessels and remote-control diving vehicles. In order to improve the technical level of the testing staff, the deep-water test range sent two groups of people abroad for additional training. During their training period, they made great advances in breaking the world deep-diving record. In 1985, the Navy successfully completed its first 200 m simulated deep dive. The Hainan Deep-Water Test Range was one of the participating units. In May and June 1988, the Hainan Deep-Water Test Range smoothly completed the deep-water launch of a self-guidance torpedo.

(5) Building Electronic Countermeasures Test Site

In order to improve electronic warfare capability of the Navy, it is necessary to conduct scientific experiments under combat conditions. In the mid-1970s, the State Council and the Central Military Commission decided to build a naval electronic warfare test site to conduct strategic and tactical tests of countermeasures equipment, to perform in-flight tests and to provide training. After surveying different areas along the coast and near inland lakes, with the approval of the Chief of Staff Command, it was built in the Bohai region. In November 1981, the test site was officially created. Fang Juzheng [2075 1446 2973] was the commander and Wang Dianlong [3769 3013 7893] was its political advisor.

To accelerate the construction of this electronic warfare test site, the Navy and the National Defense Science, Technology & Industry Commission provided funding to equipment the site with a measurement radar, infrared thermal imaging system, infrared intensity radiometer, and wide-band radar system to meet the requirements in measuring targets of different characteristics in different bands with high accuracy. In order to precisely reflect the reflection area of an interference shell, the test site built wooden launch vessels. Furthermore, it began applied research on simulated analog tests. In the meantime, it initiated an effort to resolve problems associated with multiple-target testing and the simulation testing engineering system.

In 1988, the electronic warfare test site was built up to a certain scale. A test team was formed. It has completed 62 testing assignments and tactical electronic warfare drills.

Section 2. Torpedo Tests

Modern torpedoes are concealed prior to launching a surprise attack. They hit the most vulnerable part of a

vessel below the water line. Hence, the testing is highly complex and demands a great deal from the test facility. China began to organize torpedo tests in the 1960s and solved a series of complicated technical issues associated with underwater measurement. Moreover, the testing has been extended from shallow water to deep water, and from self-control to self-guidance torpedoes. The testing organization and level continues to improve to smoothly complete various assignments.

(1) Test of Air-to-Ship, Ship-to-Ship, and Submarine-to-Ship Torpedoes

(i) Test of air-to-ship torpedoes

In November 1960, the Navy organized the first air-drop test for its jet-propelled air-to-ship torpedo in Lushun. It was a solid rocket engine torpedo which was deployed by an H-5 bomber from high altitude. Due to the poor technical level in production and testing, it was terminated because the cause of failure of the first torpedo was never found. Until the 374th Plant was constructed to exclusively manufacture air-to-ship torpedoes, the production of this model of air-to-ship torpedo was arranged.

In July-September 1969, a design-finalization test of the jet-propelledair-to-ship torpedo was organized by the Liaonan Test Range. In this test, the external trajectory was measured by three theodolites. The internal trajectory was measured with an internal tracking recorder. Explosive targets were deployed on the surface; 24 torpedoes were launched. Although some data was obtained, the tests were still not satisfactory. Later, on the basis of progress in air defense weapons, the air drop altitude was changed. The 374th Plant, Navy representatives at the plant and the Liaonan Test Range jointly conducted a study. A rudder was added to the torpedo and the top fin of the torpedo was modified to reduce the angle of entrance into the water. In March-April 1970, an air-to-ship torpedo test involving 39 torpedoes was organized by Deputy Chief Li Qiushun [2621 3061 7311] of the Torpedo Laboratory at Liaonan Test Range. The performance of the jet-propelled air-to-ship torpedo was found to meet all specifications. Consequently, it passed the design finalization test.

(ii) Test of ship (submarine)-to-ship torpedoes

In 1965, the Navy organized the first sea test of its thermally-powered self-control ship (submarine)-to-ship torpedo in Qingdao and launched more than 100 torpedoes. Because of the simple experiment setup, very little data was taken. It was more difficult to draw any precise conclusions. In 1970, the Navy organized another test on this model of torpedo in Lushun and Zhoushan. Over a period of more than a year, involving more than 615 submarines, fast boats and supply ships, over 500 torpedoes were launched. The measurement apparatus in that test was improved. Important parameters such as the cruising speed, depth, and transverse roll of the torpedo were obtained. However, the accuracy was still poor. Other ballistic parameters of the torpedo were still not available. The test was reorganized to evaluate the overall performance of this torpedo after the Liaonan Test Range was constructed. Finally, the design-finalization test for the thermally powered self-control ship (submarine)-to-ship torpedo was completed.

(2) Test of Acoustically Guided Anti-Submarine Torpedo

In 1972, Li Qiushun and Zhang Guoyi [1728 0948 5030] of the Liaonan Test Range organized the design-finalization test for a dual-plane passive acoustic anti-submarine torpedo, i.e., the Y-3 torpedo. The result showed that the torpedo design was a success. In March-October 1983, a production model finalization test for the Y-3 was done at the Liaonan Test Range. The National Defense Science, Technology & Industry Commission, Navy, China Shipbuilding Industry Corporation, and National Defense Office in Yunnan sent people to guide the test. This test was executed by director Li Anliang [2621 1344 0081] and associate directors Meng Qingji and Tian Yichun [3944 0110 2504] of the test site. The Lushun Naval Base, the North Sea Fleet and Naval Test Base collaborated with the test site. Eleven vessels, including destroyers, submarines, patrol boats, target ships and mine retrievers were used; 43 torpedoes were launched. The test results showed that all major tactical specifications such as speed, range, depth, transverse roll, effective guidance range and guidance accuracy were met. Nevertheless, problems such as malfunction in guidance tracking and the fuse trigger due to the marine environment and internal electronic interference were also found. A team comprised of development, testing personnel, and end users was organized on site to deal with the problems. Chief Designer Yang Baosheng [2799 0202 3932] and Associate Chief Designer Jiang Lainfang [3068 6647 2455] analyzed the problems with their technical staff and finally resolved all the issues to complete the test. In March 1984, a follow-up production model finalization test on the Y-3 torpedo was conducted at the Liaonan Test Range to address issues concerning the storage and use of such torpedoes onboard of a submarine. The tests listed in the outline were successfully completed. Since then, China has had its first generation of independently developed passive acoustic anti-submarine torpedoes for its nuclear-powered submarines.

In late May 1988, a deep-water test on the Y-3 torpedo launched from a nuclear submarine was done at the deep-water test range in the South China Sea. The result showed that the torpedo launch system could safely handle the launch of a torpedo at great depths. After a torpedo is launched at a great depth, its guidance system could capture its target to begin automatic tracking. If the target was lost, the torpedo could reinitiate a search to guide itself to the target. This deep-water test also demonstrated that the Y-3 was a success.

(3) Test of Acoustic Antiship Torpedo

(i) Test of the Y-4A

In March 1977, the first test to improve the design of the Y-4 torpedo was conducted at Liaonan Test Range. The overall tactical performance of the torpedo was appraised to prove that the improved design was essentially successful.

In September 1979, the newly produced Y-4 torpedo underwent its second sea test at Liaonan Test Range. Problems such as high noise in the guidance beam, unreliable depth variation and fuse malfunction at the terminal stage were found in the test. After corrective measures were taken, it was tested for the third time in June 1980. The results showed that the overall performance was excellent, the fuse was reliable and stable and the guidance beam was uniform.

In July 1981, associate director Meng Qingji of Liaonan Test Range organized a production model finalization test for the Y-4. This test involved 56 vessels, including guided missile frigates, submarines, fast patrol boats and auxiliary ships, and launched 78 torpedoes. Other than fuse malfunction, other design specifications were met. After the problem was resolved by the 874th and 872nd Plants, a follow-up test on the torpedo fuse was successfully completed in the East China Sea in December 1982. This is an improved version of China's first-generation passive guidance anti-ship torpedo.

(ii) Test of the Y-4B

From the late 1960s to the late 1970s, Northwestern Polytechnical University conducted a series of scientific experiments on the active and passive acoustic guidance, non-contact fuse and small electronic depth controller of the Y-4B. The focus was on the evaluation of the performance of the guidance system and the non-contact fuse of the torpedo and the feasibility of cruising at a great depth with stability. In March 1982, Director Li Anliang of the Liaonan Test Range organized a test on the sea to finalize the design of the Y-4B. With the collaboration of Liu Feng [0491 6912], Xie Yiqing [6200 0001 3237] and Li Zhishun [2621 1807 5293] of Northwestern Polytechnical University and the 874th and 872nd Plants, most of the items being tested went along smoothly. Major tactical and technical parameters such as overall design, guidance, fuse and depth control were found to meet our specifications. The development effort was a success. In particular, for the first time depth control was done electronically, instead of mechanically. This significantly improved the performance of the torpedo. However, it caused a scatter in its effective active self-guidance range. This problem was resolved by following the recommendation to calibrate the active guidance "time control curve" section by section proposed by Peng Haifa [1756 3189 4099] of the Liaonan Test Range and by changing the vertical attitude of the transponder transducer as proposed by Chief Zhang Shihe [1782 1709 3109] of the Liaonan Test Range.

In March 1987, the Y-4B production model finalization test was conducted at the Liaonan Test Range. The test was organized by Director Tian Yichun and Associate Director Chen Zhibin [7115 1807 1755]. Organizations involved include various departments of the Navy, Northwestern Polytechnical University, and the 872, 874 and 482 plants. A total of 58 vessels were used and 63 torpedoes were launched in this test. The results showed that all performance indicators of the torpedo met tactical and technical specifications. In this test, the "Test Procedure for Torpedo Design Finalization" written by Zhang Shihe and Tian Yichun of the Liaonan Test Range was used. Under the premise of ensuring the reliability of the test data, this procedure reduces the number of torpedoes required for such a test. It shortens the test period and improves the test efficiency.

The successful development of the Y-4B filled a void in active/passive acoustic anti-ship torpedo.

(4) Test of Light Acoustic Anti-Submarine Torpedo

In 1989, a light-weight active/passive acoustic anti-submarine torpedo was tested on a lake at the 750th test site. From September to November of the same year, it was tested for its bottom searching capability at the the Liaonan Test Range. The testing of this torpedo is more complicated. It was jointly organized by the Navy and China Shipbuilding Industry Corporation. The National Defense Science, Technology & Industry Commission sent its own staff to provide guidance. Vice Commander of the Navy, Li Jing [2621 2529], arrived at the scene to inspect the preparation work. Naval Test Base Command Wang Huique directed the test at sea. Commander Wang Chaofan [3769 6389 0416] of the naval test region acted as the test group leader. Chief Wang Ruiyuan [3769 3843 3293] of Liaonan Test Range was the deputy test leader. He was in charge of organizing the tests. In the tests, the Surveyer-2, 3 and 4 of the Nanhai Deep-Water Test Range were responsible for launching torpedoes and deploying tracking and measurement instruments. Surveyer-3 and 4 encountered very rough weather when they were deploying external trajectory tracking equipment. Gale winds exceeded level 10. They fought this kind of weather for 2 days and a night. Despite fatigue and bad weather, the safety of the ships and personnel was ensured. Furthermore, they continued to work, especially the divers, who successfully deployed the targets in strong currents at low temperature to contribute to the successful completion of the test.

With close cooperation of personnel from the Liaonan Test Range, the Nanhai Deep-Water Test Range, the 705th Institute, the 874 Plant and the 872 Plant, the test lasted 67 days. It mobilized nine ships and a helicopter. Fifteen torpedoes were fired to obtain data such as searching, tracking, researching trajectory, active self-guidance effective range, false alarm rate, torpedo speed, and tracking of a moving target. The results showed that this light active/passive acoustic anti-submarine torpedo

had met all major tactical specifications listed in the development plan. This provides the data for design finalization.

Section 3. Test of Mines and Anti-Submarine Weaponry and Equipment

The purpose of testing mines and anti-submarine weaponry and equipment is to evaluate their strategic and tactical performance in near combat situations. Due to limitations imposed by the test conditions, development tests and performance evaluations of mines are usually carried out by various naval fleets in conjunction with the development and production organizations. Since the construction of the Liaonan Test Range over 20 years ago, it has completed 43 tests on mines and deployed nearly 1,000 mines. Close to 100 armed mines were exploded. In addition, it also completed the testing of depth-charge anti-submarine systems and torpedo anti-submarine systems.

(1) Test of Mines

Location is the difficult task in mine tests. Not only does a moving target need to be located but also the position of an underwater mine must be determined. They require a long period of time. Usually, it requires 6-8 hours to continuously locate the target and mines. There is a large variety of mines and each requires a different test method.

(i) Mine explosion tests

The pressure and power of an exploding mine are of interest. To solve this problem, more than 100 anchored mines, drift mines, and sunk mines loaded with different amounts of charges were exploded at the Liaonan Test Range between July 1970 and October 1988. A number of explosion pressure measurement systems, such as a digital remote explosion pressure sensing system and a microcomputer-based underwater explosion pressure monitoring system, were used in the test. The results showed that mines developed by China are very powerful and destructive. The effective radius of the fuse is consistent with the destructive radius of the explosive. In the meantime, the tests also provided valuable data for the development of new mine fuses and ship designs.

(ii) Tests of M-1B mine

The M-1B mine was a modified version of the M-1 mine. It was developed by the 701st Institute of the Seventh Research Academy by adding a displacement acoustic fuse to the M-1. Its design-finalization test was performed in September through December 1981 at the Liaonan Test Range. This test involved the use of frigates to drop 21 depth charges and two armed mines. It evaluated the M-1B's resistance against an exploding neighboring mine, fuse action, resistance against depth charges and falling off target. The results showed that the mine essentially met all tactical specifications. After the development took measures to correct the problems surfaced during the test, a follow-up design-finalization test was done in March-May 1982. It was a success. The development of the M-1B has a significant military advantage in terms of enhanced active attack of contact mines and expanded useful area.

(iii) Test of microprocessor-based combination mines

In June-August 1985, the first-generation microprocessor-based mine developed by the Dalian Surface Vessel Design Institute of the Navy was tested at the Liaonan Test Range. The outcome indicated that the design of the microprocessor-based combination mine was sound. This test showed that it was possible to consolidate all kinds of fuses for a bottom mine to have a programmable combination fuse that has a unique feature to alter the capability of the mine. Then, one mine can be used to replace a variety of mines. It had a revolutionary impact on mine development.

(iv) Test of rocket engine rising mine

Between 1985 and December 1986, the first-generation rocket engine rising mine developed by the 710th Institute of the Seventh Research Academy was tested at the Liaonan Test Range. This test was organized by the mine testing laboratory of the Liaonan Test Range. People from relevant department of the Navy, China Shipbuilding Industry Corporation, the Seventh Research Academy, the 710th Institute and the 884 Plant also participated the test. A number of destroyers, frigates, and submarine hunters were used to deploy 20 large depth charges and one armed mine; 42 mines were tested. Furthermore, experimental data was effectively recorded from various instruments such as a mine fuse tester, a NC-2 internal measurement device, a Model 7910 mine fuse remote tester and an electronic radio location system. The test followed the "test procedure for mine design finalization" written by Liaonan Test Range Senior Engineer Wang Shiming [3769 0013 2494] and Li Dexu [2621 1795 2485]. The test proved that all major tactical characteristics such as mine floating, fuse separation, regional property, resistance against sweeping, current resistance, underwater explosion resistance and overall deployment, have met combat requirements. In October-December 1989, a production model finalization test was conducted at the Liaonan Test Range. It was found that the performance of this rocket engine floating mine is at an advanced domestic level.

(2) Test of Anti-Submarine Weapon Systems

An anti-submarine weapon system is usually comprised of a sonar detector, control panel, launch devices, and depth charges or torpedoes. As progress is being made in science and technology, submarines are also becoming more sophisticated. During the process of development of naval weapons, China also developed and tested some anti-submarine weapon systems.

(i) Test of the 2500 depth-charge anti-submarine system

The 2500 depth-charge anti-submarine system consists of 10 subsystems, including a sonar, depth-charge-firing

control panel, rocket engine depth-charge launcher, electric aiming device, charge thrower, large depth-charge launcher and depth-charge deployment stand. In December 1975, a bow attack test of the system was carried out in Taiqinggong, Qingdao. In January 1976, a stern attack test of the system was done in Lushun. It was found that the 2500 depth-charge anti-submarine system operated reliably and stably. Its tactical performance is close to that of comparable systems made abroad. In May-June 1982 and March-June 1983, two design-finalization tests for the 2500 depth-charge anti-submarine system were conducted at the Liaonan Test Range. Both tests were organized by Chief of Staff Gao Fusheng [7559 1381 3932] and Director Chen Yutang [7115 3768 1016]. The tests involved 35 frigates and destroyers and six helicopters and launched 160 rocket depth charges in accuracy tests and actual firing tests. In the tests, optical instruments were used on land and synchronous cameras were used on ships to record the relevant data. In addition, helicopter-mounted cameras were used to pinpoint locations where the rocket-propelled depth charges fell. The results showed that the accuracy of the 2500 depth-charge anti-submarine system could meet its major tactical requirements.

(ii) Test of digital control panel depth-charge anti-submarine system

In March-May 1981, the digital control panel of the anti-submarine depth charge developed by the 716th Institute of the 7th Research Academy was tested in the East China Sea. From December 1983 to January 1984, a Model 2500 depth-charge anti-submarine system equipped with such a digital control panel was tested at the Liaonan Test Range. The digital control panel was found to work smoothly and reliably. The 2500 anti-submarine depth-charge system equipped with the digital control panel is more reliable and accurate in use.

(iii) Test of anti-submarine torpedo system

From August 1975 to January 1976, an anti-submarine torpedo system was tested in two stages at the Liaonan Test Range. The first stage was to perform actual and simulated torpedo launching from a submarine using a periscope. The second stage involved the launch of Y-3 torpedoes from a nuclear-powered submarine against surface ships. The results showed that both actual and simulated torpedo launches were successful. The submarine-based torpedo system could function smoothly and stably with an accuracy that meets requirements.

Section 4. Test of Ship Gun Weapon System

(1) Test of Twin 37mm Ship Gun Weapon System

At the end of 1980, the twin 37mm ship gun weapon system was tested at the Liaoxi Ship Gun Test Range. The test was carried out in two stages on land and at sea. The Liaoxi Ship Gun Test Range did a great deal of technical preparation work on testing technique, measurement, timing, target, weather and operator training to complete the land test. In the tests, the weapon system was found to be unstable. The cause was identified by the development unit and the Liaoxi Ship Gun Test Range. After taking corrective measures, it was retested in April 1981. All items listed in the outline were smoothly completed. The land test results showed that every tactical specification was essentially met and it was ready for design-finalization tests at sea.

In mid-December 1982, the twin 37mm ship gun weapon system underwent design-finalization testing at the Liaoxi Ship Gun Test Range. The tests progressed in the order of dynamic problem solving, fixed surface target gunnery and remote control drone gunnery. The problem-solving part passed and there was a high percentage of hits on the targets. The twin 37mm ship gun primarily relied on the calibration method to improve its accuracy for an air target. Since weather reports were not available to the antiaircraft gunners, it was impossible to fire accurately. Later, in a simulated firing test after adopting a scheme proposed by Zhu Xibin [2612 6932 2430] of the Systems Engineering Department of China Shipbuilding Industry Corporation, the accuracy was significantly improved. Satisfactory results were obtained in a drone firing test. The design-finalization testing was successfully completed in December of the same year. All tactical specifications have met design requirements. During the same period, the design-finalization testing was completed on land and at sea for a similar twin 30mm ship gun weapon system.

The test of the twin 37mm ship gun weapon system II that is used to shoot down anti-ship missiles was tested at the Liaoxi Ship Gun Test Range in October 1987. In this test, in addition to completing various technical preparation work, an ultralow target with a reflective area of 0.1 meter square and a low-altitude towed target were deployed, a digital automatic recorder was developed and an experimental scheme to suppress the dynamic accuracy of a small area ultralow-altitude target to allow the test to proceed smoothly. On this basis, the power, resolution, reaction time and dynamic tacking accuracy of the twin 37mm ship gun II with reference to low-altitude and ultralow-altitude targets were investigated. It was found that this ship gun system could detect and track targets in time. Its accuracy against low-altitude towed targets was excellent.

(2) Test of Twin 100mm Ship Gun Weapon System

Design-finalization testing for the twin 100mm ship gun weapon system was conducted in two stages; on land and at sea. The stage done on land was primarily focused on its dynamic accuracy and the sea phase was to evaluate its firing accuracy. Its reliability and tactical performance were tested throughout the entire process.

In May 1982, the twin 100mm ship gun was tested on land at the Liaoxi Ship Gun Test Range. This included dynamic accuracy tests with reference to constant-speed

targets traveling straight on the sea, targets flying horizontally at constant speed, and diving targets. The test results on targets at sea show that this ship gun system is reliable, stable, and accurate enough to meet all specifications.

In 1983, the twin 100mm ship gun was equipped with the first medium-caliber automatic shell supply system independently developed by China. After going through anchoring test, static and dynamic problem solving at high speed, and functional drill at sea, the service behavior of the twin 100mm ship gun was further evaluated under intense longitudinal and transverse rolling. In addition, it also underwent firing accuracy tests using fixed surface targets, towed targets, and remote control drones.

The twin 100mm ship gun weapon system passed two stages of rigorous test, including close to 200 dynamic accuracy tests and firing nearly 1,000 rounds in the gunnery tests. It was proved to meet all design specifications. It is stable, reliable, accurate and could work automatically around the clock in all weather conditions.

From 1972 through 1987, the Liaoxi Ship Gun Test Range organized tests on 6 different ship guns in 3 different calibers, 7 models of radars of 2 different types, 7 models of control panels of 3 different kinds, and 5 models of ship gun weapon systems in 3 different calibers. In addition, on the basis of its experience, they also prepared the "test procedure for the design finalization of ship gun weapon system," "test procedure for the design finalization of tracking radar," "test procedure for the design finalization of ship gun firing control panel," and "test procedure for the design finalization of ship gun weapon system on the sea."

(3) Testing of Twin 130mm Ship Gun Weapon System

In 1971, the digitally controlled twin 130mm ship gun weapon system developed by the 368 Plant needed to be tested. The Liaoxi Ship Gun Test Range had just been constructed. The plant created a test team by pulling technical talent from different organizations. They were trained at Baicheng Conventional Weapon Test Range while they prepared for this task. In the fall of 1972, the twin 130mm ship gun system was tested for the first time at the Liaoxi Ship Gun Test Range. Due to lack of experience, it was directly installed on a ship to conduct test at sea without going through any land tests. Consequently, major technical problems such as lack of coordination were encountered. The test was terminated. A review of this experience led us to understand and follow the procedure that land tests must be conducted before any test can be conducted at sea.

In 1973, the Liaoxi Ship Gun Test Range began to test the twin 130mm ship gun system on land to verify the feasibility, coordination, and stability of the system, and to evaluate the dynamic accuracy of the system using the sea surface as a background. The land accuracy test had to be conducted using model sea combat conditions; ultralow-altitude targets were used to simulate anti-ship missiles. These were the difficulties of the test. In particular, it was necessary to determine accurately any deviation from every theoretical factor. After numerous attempts, Yang Banglin [2799 2831 2651] at the test range wrote a program entitled "solution to theoretical values of various firing factors" to solve this problem. In 1973, the testing of individual units of radar, control panel and ship gun began. In 1975, design-finalization testing of the entire system was conducted. Through dynamic accuracy test using ships and aircraft as targets, and target practice using fixed surface targets and towed targets, the performance of the twin 130mm ship gun weapon system was evaluated. The test results showed that the system worked smoothly with excellent accuracy. The plan was feasible, but not very reliable.

In October 1980, the twin 130mm ship gun system was tested at sea at the Liaoxi Ship Gun Test Range. The focal point and difficulty was its firing accuracy test. Based on the experience acquired in gunnery tests on water, an aerial camera was used to measure the actual distance between the water splash and the bull's eye to obtain the relevant parameters to calculate the range and bearing deviation. Thus, the key technical issue with regard to the accuracy test at sea was resolved. After it was qualified for tracking accuracy, its firing accuracy was tested using fixed and towed targets. Finally, a remote control target ship was used to test its firepower in real combat situations. While it was found that the system was highly accurate, it was still not very reliable. After the systems were modified to a multi-processor distributive function ship gun system using brand-new, highly reliable components and technology by the 713rd Institute and the 368th Plant, it was tested in Zhoushan in 1986. After a number of target practice tests using fixed and towed targets, the capability of this ship gun system was substantially enhanced. It was more reliable and accurate.

Section 5. Testing of Navigational Equipment

There is a variety of navigational equipment. Furthermore, it needs to be tested under dynamic conditions in the ocean, which makes its testing more difficult. The navigational equipment test laboratory of the naval test base, in collaboration with the appropriate institutes and factories, developed a variety of dynamic bearing and level measuring instruments and high-precision inertial navigational equipment for ship use. It imported a highly accurate ship location measuring device that solved the problems associated with measuring such navigational parameters as bearing, transverse rocking angle, longitudinal rocking angle, ship location and cruising speed under different test conditions. It created the necessary condition for the successful testing of navigational equipment.

(1) Testing of Radio Navigational Equipment and Combined Navigational Equipment

From July to October 1970, the navigational equipment test laboratory organized a test of the "Changhe 3" radio navigational equipment. Because the only instrument available was an optical theodolite, the test was severely affected by the weather and visibility. Furthermore, the cruising range of the test ship was limited. It was impossible to provide real time results. The experimental period was extended. In May 1984, the navigational equipment test laboratory simultaneously conducted the design-finalization tests for two models of satellite/Omega combined navigational equipment developed by the 765th Plant and the 750th Plant and by the 20th Institute of the 10th Research Academy, respectively. The location accuracy of the satellite/Omega combined systems were checked against that of the high-accuracy radio location equipment. It was found that its accuracy met the design specification.

(2) Testing of Platform Compass

In July 1970, the navigational equipment test laboratory conducted a development test of the 502 platform compass at sea to validate its feasibility. Due to the use of outdated equipment and test methods, it failed. This failure brought us some beneficial experience and a valuable lesson. After 1971, the navigational equipment test laboratory concentrated on the development of precision measurement instrumentation for bearing and level. Some results were obtained. Su Laizhi [5685 0171 0037] proposed a dual display angle measuring platform which solved the problem associated with the measurement of bearing accuracy under different dynamic conditions. It minimized the effect of rocking on the bearing measurement. However, it could not provide a real-time answer. Yao Shaoshi [1202 1421 1102] proposed using a long-focal-length aerial camera and a high-precision measurement system to form a level accuracy measurement scheme. Furthermore, he proposed using a joint base to overcome the effect of hull distortion during rocking on the measurement of level accuracy in order to solve the problem of measuring level accuracy under dynamics conditions. At the same time, the navigational equipment test laboratory was also doing research on test methods, equipment installation, and calibration and accuracy evaluation.

From 1975 to 1989, the navigational equipment test laboratory conducted developmental tests, accuracy evaluation tests and design-finalization tests for five platform compasses, including the H/HPL-001 developed by the 455 Plant and 457 Plant, the H/HPL-002 developed by the 707 Institute, and the H/HPL-003 developed by the 442 Plant and Harbin Institute of Shipbuilding. These tests involved numerous tasks, multiple voyages, and long test cycles. In order to speed up the tests, they worked day and night to take advantage of better weather conditions. In some cases, they went to sea 6 days a week to complete assignments on time.

(3) Testing of Inertial Navigation Systems

An inertial navigation system provides parameters such as bearing, transverse rocking angle, longitudinal rocking angle, cruising speed, northerly speed, easterly speed and ship location. It is a piece of independent, highly accurate navigational equipment. It requires extremely high accuracy and long testing periods.

In the fourth quarter of 1976, the navigational equipment test laboratory conducted its initial development test on the 915-IIA inertial navigational equipment to validate its design and inspect the accuracy of each navigational parameter. The test results showed that the design was feasible. However, the accuracy was poor. In 1978 and 1983, tests were done on the 915-IIA and 915-IIB inertial navigational equipment for accuracy. Due to technical reasons associated with the inertial navigational systems and outdated measurement technique, the tests did not generate the desired result. In 1985, the navigational equipment test laboratory again conducted six tests on the two models described above. Because of the high-accuracy radio location equipment used, and also because the two systems were improved somewhat, excellent results were obtained.

In 1986, the navigational equipment test laboratory of the Naval Test Base performed incoming inspection for imported navigational equipment over a period of 3 years to check its accuracy and reliability. In order to complete the inspection work within the period specified in the contract, director Yao Shaoshi proposed a scheme to simultaneously record and process bearing accuracy data independently. They developed the necessary equipment for real-time data acquisition. In addition, any error and the technical condition of the product being inspected can be reviewed immediately. A specific course and a particular mode of ship motion that can produce the largest error are chosen to conduct the test. Once a problem was discovered, it was immediately brought to the attention of the technical staff of the manufacturer. The data is used as the evidence to assess the actual level of the product being inspected.

The navigational equipment test laboratory insists on quality. Problems are exposed by testing. They often assist development units to locate the source in order to find a fix. In March 1988, during a check of the 915-IID navigational test equipment, it was found that the ship location accuracy error was excessive. The navigational equipment test laboratory conducted analysis, testing, and verification at the same time and finally found the source of the problem. The 707th Institute adopted a number of technical measures to solve the problem and the quality of the product was improved.

From 1976 to 1989, the navigational equipment test laboratory tested four models of navigational equipment. During the course, in order to meet the stringent accuracy requirement, especially in bearing and level accuracy measurement, it was necessary to develop a set

of automated high-accuracy shipboard inertial navigational equipment. On the basis of a comprehensive survey and concept validation, Zheng Zizhen [6774 2737 4394] presented an astronavigation scheme that is comprised of a microcomputer, an astro-theodolite and a high-accuracy radio locator. This is a highly accurate, automated dynamic real-time inertial navigational system that combines optics, mechanics, electronics and microelectronics. Its use not only completed the assignment but also improved the degree of automation of the test.

Chapter XXVI

Section 1. Metallic Materials for Military Use

(5) Metallic Panel Material

The injector plate is a critical component of a the injector system of a liquid hydrogen/liquid oxygen engine. It operates in a hostile environment: not only must it work at high temperatures up to 3,000-3,500°C but also at low temperatures below 100-150°C. This challenging task was jointly tackled by the Beijing Institute of Steel Research, Taiyuan Steel Works, Tianjin Institute of Metallurgy, Tianjin Experimental Metal Works and Beijing Institute of Aerospace Materials. After repeated testing, the composite face plate was successfully used on the Long March-3 rocket. Its performance characteristics are more advanced than those for comparable products made by other countries.

(6) Metallic Material and Pressure-Resistant Hull Material for Submarines

Due to its excellent heat-conduction properties, copper alloy is widely used in submarine heat exchangers. It must be capable of withstanding high pressure, as well as impact and corrosion from sea water when the submarine is cruising at high speed, to ensure its integrity during use. In order to supply the white brass for the main and auxiliary condensers, the technical staff at the Luoyang Copper Processing Plant, with the cooperation of the Luoyang Institute of Shipbuilding Materials, developed two different grades of white brass condenser tube in just over a year to meet an urgent need in submarine construction. On this basis, the Luoyang Copper Processing Plant used an RF induction furnace to melt copper and a low-frequency oven to maintain its temperature. It was cast in a semi-continuous manner. Zirconium was added to solve the crystallization problem. They successfully developed a more superior condensed white brass plate. At the same time, the team at the Luoyang Copper Processing Plant added small amounts of metallic elements in the condensed white brass to strengthen the plate. It solved the strength requirement in hot rolling to meet a need in submarine development.

Pressure-Resistant Hull Material

In 1960, Anshan Iron and Steel began to develop 921, 922 and 923 steel with a yield strength on the order of 60 kg. Until 1966, a breakthrough was made to meet all technical specifications. In addition, a high-strength, highly malleable, radiation-resistant steel that can be welded was developed as a pressure-resistant hull material. A new stress corrosion resistant alloy tube developed by Beijing Institute of Steel Research and Shanghai Fifth Iron and Steel Plant is used in submarine evaporators. It was given a first place national science and technology progress award.

(7) Friction-Reduction Materials

In the 1960s, Beijing Institute of Steel Research, Shanghai Institute of Non-Ferrous Metals, Central China Institute of Metallurgy and Beijing Institute of Powder Metallurgy were engaged in research on friction-reduction materials for specific circumstances. A number of accomplishments were obtained. In the early 1970s a dynamically sealed graphite lubricant and a metal/plastic composite lubricant were developed for combustion turbine and jet engines for aircraft use. The latter has advantages such as low friction coefficient, low erosion, high strength, good thermal conductivity and a small thermal expansion coefficient similar to those of a fluorine containing plastic. It is suitable to operate in a vacuum, at low temperature and in an inert-gas environment. It has been successfully used in aerospace applications. Its performance characteristics are at an advanced level compared to similar products made abroad. A boron-carbide pneumatic bearing, developed in the late 1970s for aerospace and ship applications, has advantages such as high density, high hardness, low specific gravity, high erosion and pinch resistance, high corrosion resistance, and low static friction coefficient. Its dimensions remain stable after long periods of use at high temperatures and it can be stopped and started for more than 10,000 times. In the early 1980s, a high-temperature vacuum self-lubricating bearing material for an agile-frequency magnetron and a floating seal material for rocket engine fuel were developed.

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